

Tiltmeter Mapping of Steam Zones During Steam Injection February–June 1993

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TILTMETER MAPPING OF STEAM ZONES
DURING STEAM INJECTION
FEBRUARY - JUNE 1993

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SUMMARY

An array of 17 high gain tiltmeters was installed at Lawrence Livermore National Laboratory in the area around building 406 in July 1992, for the monitoring of steam injection to clean up a contaminated aquifer at the Gas Pad.

Tiltmeter mapping of hydrologic tests was performed in August 1992, and steam injection was monitored between February and June 1993.

This report describes the results of the hydrologic testing and the monitoring of the steam injection. Detailed figures showing the growth of the steam zones during each cycle of steam injection are included.

BACKGROUND AND INTRODUCTION

Tiltmeters have historically been used to map deliberately induced hydraulic fractures (ref 1). The method was however limited to the analysis of surface deformations resulting from the dislocation of the rock itself.

During hydraulic fracturing, fluid may leak off into the reservoir below parting pressure. The reservoir expansion due to this leak off also causes surface deformations, but these were either ignored or filtered out using a method such as that of Palmer (ref 2).

The authors of this report have invented methods for tiltmeter analysis of deformations resulting from fluid pressure changes below parting pressure. These are a function of both fluid and rock properties. This may not only extend the application of tiltmeter mapping during hydraulic fracturing, but also permits the use of tiltmeters for the analysis of well tests. These methods are proprietary, and patent applications are in progress, so they cannot be described here.

In January 1992, experiments were performed at the DUSP's clean site. Injection and production tests on well EW-SNL-707 confirmed that tiltmeters could repeatably detect the effects of pressure transients in a radially inhomogeneous reservoir. It also confirmed that existing tiltmeter methods were not applicable.

During dynamic underground stripping, steam is injected at one or more injection wells to mobilize contaminants towards extraction wells. Knowledge of the shape of the steam zone helps to optimize the process, and LLNL contract B200606 provided for tiltmeter mapping of the steam zone. Since this was experimental, the tiltmeter array was designed to allow qualitative data interpretation as a backup. The general concept was to have two rings of tiltmeters around the area of interest - the gas pad.

In July 1992 an array of 17 tiltmeters was installed, and figure 1 is a sketch map showing the tiltmeter locations. It can be seen that the actual locations were picked to be clear of roadways etc.. Figure 2 shows the tiltmeters together with the six injection and three production wells. Detailed survey data may be found in table 1. Note that surface elevations and tiltmeter burial depths are also reported in table 1 since these must be accounted for in the tilt data analysis.

The area to be cleaned by dynamic stripping consisted of two zones: the upper zone at approximately 80 feet deep, and the lower zone at approximately 120 feet. The free water level was in the upper zone. In August 1992 the tiltmeters were used to map hydrologic tests on all six lower injectors and one upper injector. This work was described in the informal report of 20 August 1992, and Appendix A summarises the analysis of the data.

STEAM ZONE MAPPING

GENERAL

Two cycles of steam injection were performed, the first during February and March, and the second during June, 1993. Figures 3 and 4 show the timing of injection into each upper (U) and lower (L) zone injector. Refer to figure 2 for well locations. The two types of tiltmeter monitoring are summarised below, as are the two steam cycles.

PRESSURE TRANSIENT ANALYSIS

Pressure transients were generated by shutting each injector in for one hour, and figures 3 and 4 show the timing of the shut in tests. The shut in tests were initially somewhat intermittent, increasing to a routine two shut in tests per night by the end of the first steam cycle, and to four per night by the end of the second steam cycle. The tests were performed at night to minimize the levels of background noise.

Figure 5 shows the tilt vectors resulting from a good shut in test. There were problems with a number of the tests because when one well was shut in there was an increase in the injection rate at one or more other wells. Figure 6 shows the tilt vectors from such a test. Figures 3 and 4 indicate which shut in tests were deemed to be unuseable.

Shut in tests performed early in the steam cycle yielded generally better data than those performed later in the cycle. This was due to the reservoir pressure increasing, as a result of which the drawdown (the difference between the injection and reservoir pressures) decreased. The size of the pressure transients (and hence the tilt signal) appears to have decreased by at least an order of magnitude during each steam cycle.

Figures 7 to 76 show the results of tiltmeter analysis of the shut in tests. Each test was analysed to determine the distance of the steam front from the injection well in each of six directions, and this is shown as a hatched area in each direction around the well.

Where the test data quality are poor, the apparent steam zone is hatched at half density. The reliability of such steam maps is questionable and should be treated with due caution.

In all cases two analyses were performed assuming uniform reservoir properties. For the lower zones one or two additional analyses were performed, using reservoir properties derived from the hydrologic tests. The first used properties derived from tilt data alone, while the second included observed pressure changes at other wells during the hydrologic test.

Theoretical steam radii were calculated using published equations (ref 3).

LONG TERM TILT DATA

These were monitored daily as a back up. It was also thought that the approach of the steam zone to individual tiltmeters might be revealed in the long term data. There was insufficient scope in the contract to permit detailed reporting of the long term data, but two figures are included for illustration.

Figure 77 shows long term data for channels 1 and 2 (Tiltmeter 01 East-West and North-South), during the first steam cycle of the lower zone. The figure shows an initial null period prior to mobilization, followed by background data. The initial effect of steam injection (starting at 0930 on 4 February) is clearly seen. The subsequent rollover of the trend is interpreted as the steam zone approaching and passing under the tiltmeter site. It may be noted that steam was detected at monitoring well TEP001 (just a few feet away) at approximately the same time as the rollover.

Figure 78 is a long term vector map showing the total tilt change since the start of the steam cycle. This agrees qualitatively with the steam map for the same day (figure 40) which was based on 1 hour shut in tests.

LOWER ZONE, 1st STEAM CYCLE (figures 7 - 21)

Steam injection into all six lower injectors started on 4 February, but the first shut in tests were not performed until the 7th. Shut in tests were intermittent during this cycle, so all test data was used even if the quality was poor. The steam maps suggest that a large proportion of the steam was moving outwards rather than in towards the producers, especially at wells 813, 814, 818, and 820. The hydrologic tests indicate that for these wells the preferential flow path is in a direction other than in towards the centre. For wells 815 and 819, the hydrologic tests indicate rather uniform properties around the well. (Refer to Appendix A, figures A1 and A2 for results of the hydrologic tests).

Actual flow directions also depend on the pressure gradients. During this cycle, extraction and injection were matched on a mass (rather than volumetric) basis. This means that, at least prior to steam breakthrough, injected volumes greatly exceeded produced volumes; and this also would have tended to result in flow outwards from the injectors.

UPPER ZONE, 1st STEAM CYCLE (figures 22 - 36)

All six upper injectors were brought on stream on 17 February, while the six lower injectors continued on stream. Shut in tests started immediately, but with injection divided between twice as many wells the tilt signals were proportionately smaller. Initial steam flow appears to have been mostly in towards the producers. While there is no hydrologic data for these wells, it is possible that this was the preferential flow path. It may also be that if the producers were commingled then they had been depleting the upper zone for the previous two weeks thus establishing a favourable pressure gradient. The lower zone injectors were shut in on 26 February, and the data quality of upper zone shut in tests after that date is generally poor. This may be due to the problems discussed under 'pressure transient analysis' above.

LOWER ZONE, 2nd STEAM CYCLE. (figures 37 - 61)

This cycle involved three periods of injection into selected wells (see figure 4). The producers were brought on stream well in advance of the start of injection to establish a pressure gradient. Two wells, 815 and 820, were brought on stream on 2 June. The shut in tests of 3 June (figure 38) show that the pressure transients were in each case 'seeing' the steam zone of the other well, and steam appeared to be approaching the producers. Well 818 was brought on stream on 6 June, and immediately 'saw' steam across towards the other two injectors and down towards the producers, tending to confirm the earlier steam maps. All three wells were shut in on 7 June.

Lower zone injection started again on 16 June. The number of shut in tests was increased to 4 per day, which meant that some wells were tested more than once in a day. Two steam maps per day are therefore shown from 16 June onwards. Steam flow initially appeared to be more or less radial around the injectors; but at 813 and 820 this seems to have developed into an 'away from the centre' pattern similar to the first cycle.

The final lower zone injection commenced at 814 on 25 June. The data quality for many of the shut in tests during this period of injection was rather poor. While 814 was the only well on stream its steam moved towards the producers more than during previous periods of injection. After the next well (813) was brought on stream, no further good data was obtained from 814. The other wells were only tested once or twice, so it is difficult to see any particular pattern emerging.

UPPER ZONE, 2nd STEAM CYCLE (figures 62 - 76)

This consisted of two periods of injection (figure 4). 815U and 820U came on stream on 7 June, and showed similar behaviour to 815L and 820L in the lower zones. The other four wells were brought on over the next few days. As with the first upper zone cycle, the steam tended to move radially or towards the producers.

The final upper zone injection started with GIW814U on 25 June. The analyses of the shut in tests for this period are a little inconsistent, but a large proportion of the steam from 814 seems to have moved towards the producers. Well 813 came on stream on 27 June and no good tests were obtained from 814 thereafter. The steam from 813 does not appear to have moved much towards the producers.

REFERENCES

- 1, Wood M.D., June 9 1981, 'Method of determining change in the subsurface structure due to application of fluid pressure to the Earth'. U.S. Patent No. 4271696
- 2, Palmer I.D., 'Uplifts and Tilts at Earth's Surface Induced by Pressure Transients from Hydraulic Fractures', SPE Production Engineering (August 1990), 324
- 3, Prats M, 'Thermal Recovery', Society of Petroleum Engineers Monograph Volume 7 (1982) ISBN 0-89520-314-6
Equations 5.3, 5.6, 7.10 - 7.15

TILTMETER AND WELL LOCATIONS

(Referenced to GEW816)

Based on information provided by LLNL

	Eastings (ft)	Northings (ft)	Surface Depth (ft)	Depth of Burial (ft)	
Tiltmeters					
01	110.8	-35.4	-1.2	8.0	
02	119.8	11.1	-1.1	7.2	
03	182.6	93.4	0.2	7.7	
04	69.5	106.1	2.4	8.0	
05	46.4	205.0	3.8	8.3	
06	-28.8	71.9	2.3	4.0	
07	-126.2	162.4	3.5	7.8	
08	-122.5	71.3	2.6	6.6	
09	-164.9	70.1	2.6	8.0	
10	-120.5	-8.8	1.9	7.6	
11	-98.7	-36.7	0.8	8.4	
12	-168.0	-169.6	-1.1	7.6	
13	-80.7	-196.9	-5.5	8.0	
14	0.9	-165.3	-3.1	8.3	
15	116.7	-185.6	-6.1	7.7	
16	179.7	-165.1	-4.2	7.0	
17	-27.3	231.0	3.7	8.0	
Wells				Slotted Screen Depths (ft)	
GSW16	11.3	8.1	-0.4	23.0-130.0	
GEW808	2.8	12.8	0.3	60.0-140.0	
GEW816	0.0	0.0	0.0	60.0-140.0	
GIW813	66.3	-66.3	-1.8	67.0-87.0	107.0-127.0
GIW814	-54.3	-67.1	-0.2	86.5-106.5	121.0-141.0
GIW815	88.0	-3.8	-0.8	77.0-97.0	112.5-132.5
GIW818	-9.7	57.9	1.9	82.0-102.0	120.0-140.0
GIW819	-34.6	12.3	1.5	78.6-98.6	121.0-141.0
GIW820	67.0	46.7	1.0	85.0-105.0	112.0-132.0

Note 1: Surface Depth is the Depth of the ground Surface at the Tiltmeter or Well below that at GEW816. (GSW16 is 1987 survey shiner elevation, may not be ground surface).

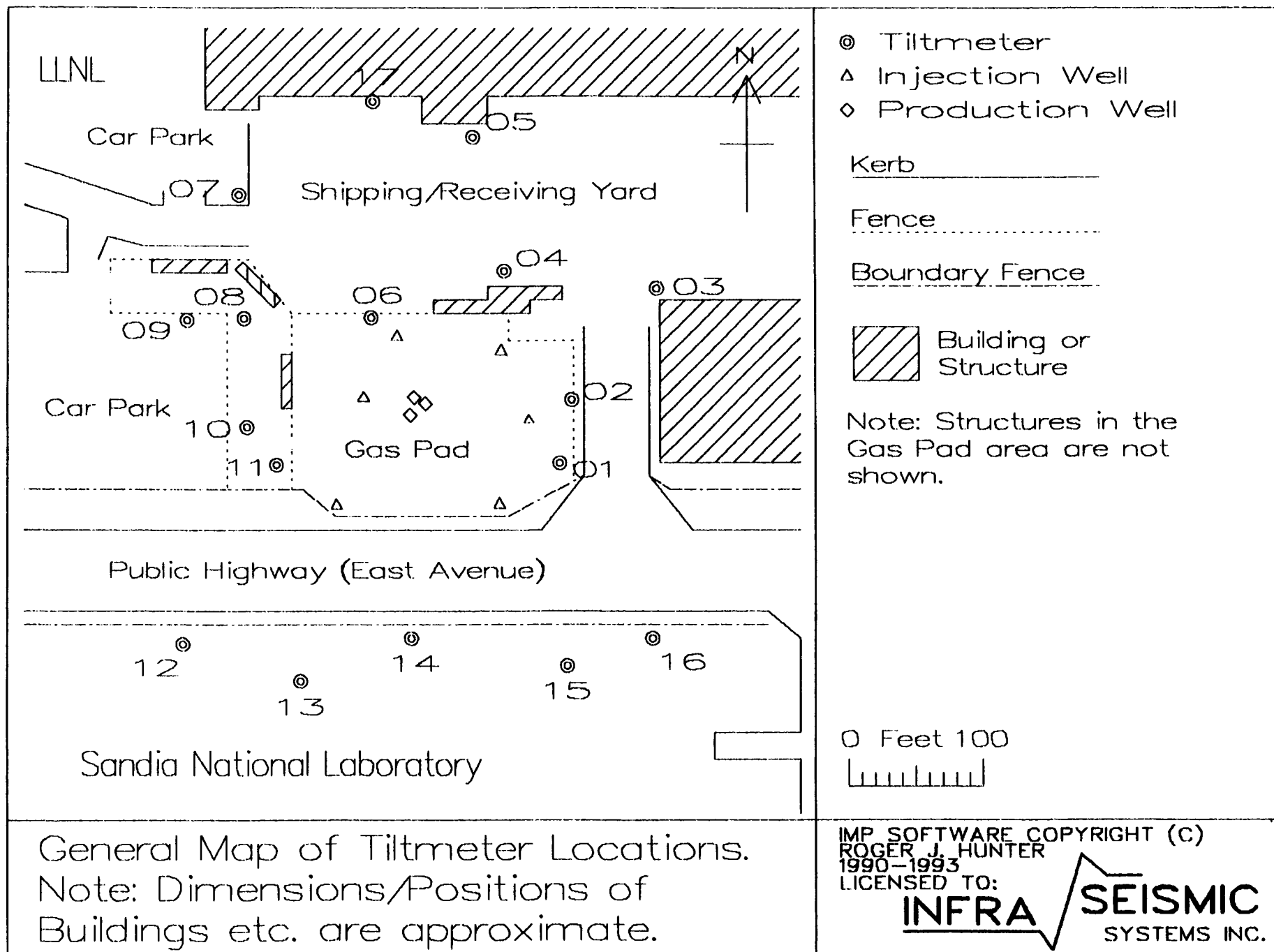
Note 2: For Tiltmeters, the Depth of Burial is the depth of the Tiltmeter below the Surface at the Tiltmeter Site.

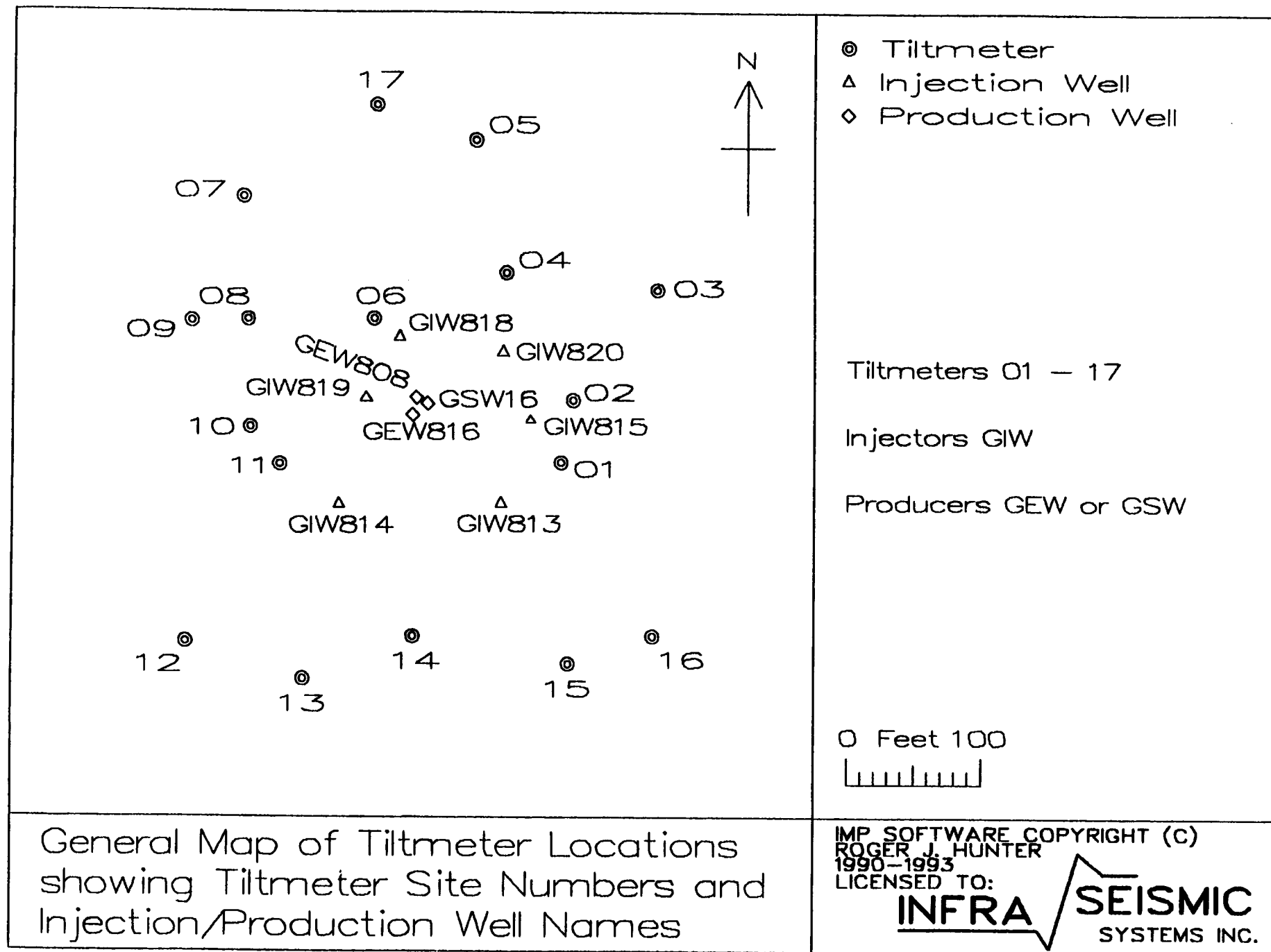
Note 3: Slotted Screen Depths are Driller's Depths below surface. Producers are commingled. Injectors are dual completions, and in the main body of the report are referenced with the suffix U (upper) or L (lower). GSW16 has 7 screen intervals reported between 23 and 130 ft, vis: 23-28, 38-43, 50-55, 61-66, 78-83, 95-105, 120-130 ft.

Note 4: Tiltmeters were aligned to true North. No correction for magnetic North is required.

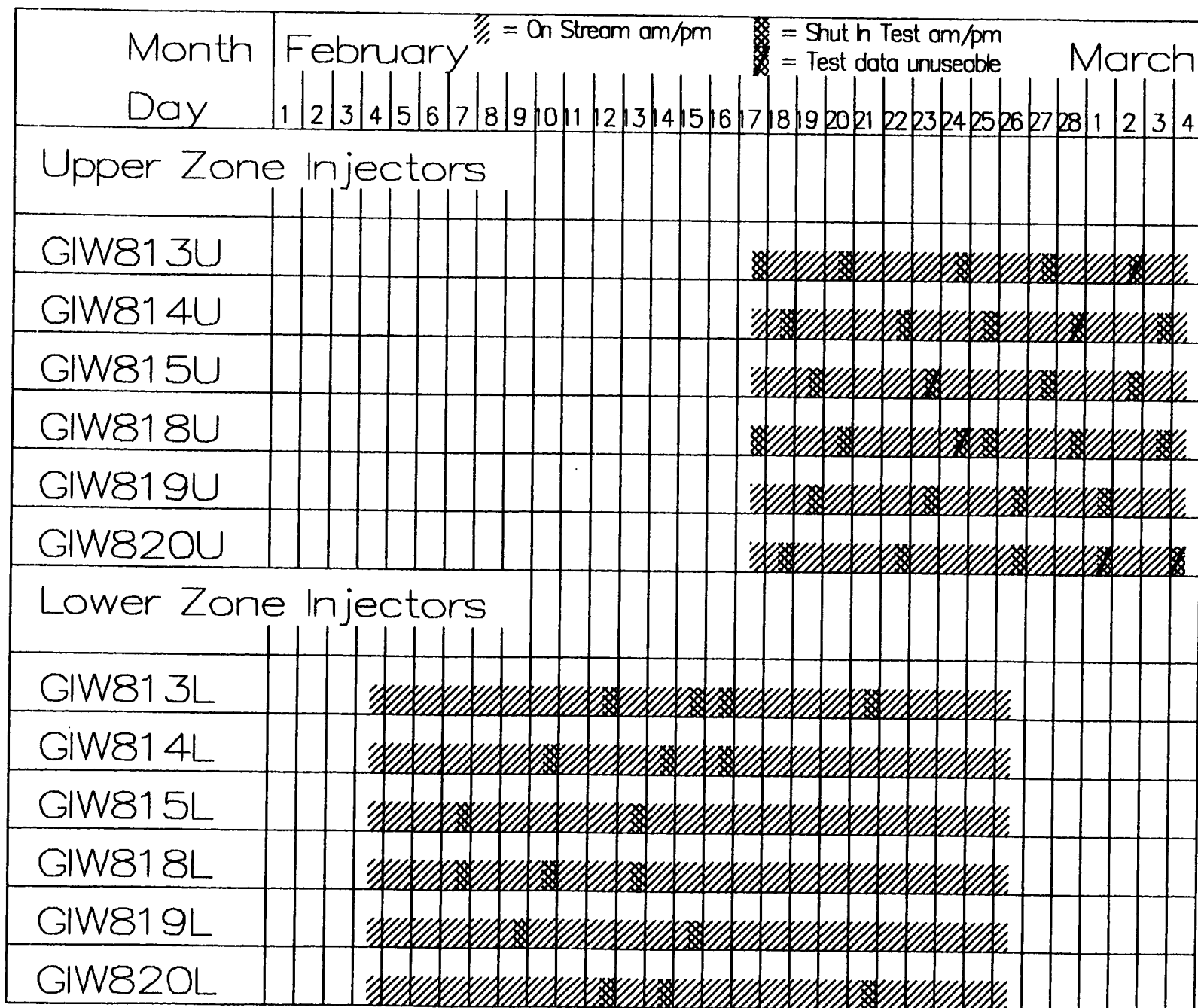
TILTMETER CALIBRATION FACTORS
(milliVolts per microRadian)

Site Number	X Channel East-West	Y Channel North-South
01	463	529
02	633	434
03	732	835
04	1447	1225
05	980	528
06	536	552
07	1140	423
08	1384	1089
09	696	494
10	332	441
11	1448	848
12	569	731
13	986	705
14	732	701
15	823	987
16	815	938
17	832	731





Steam Injection History, First Steam Cycle



Steam Injection History, Second Steam Cycle

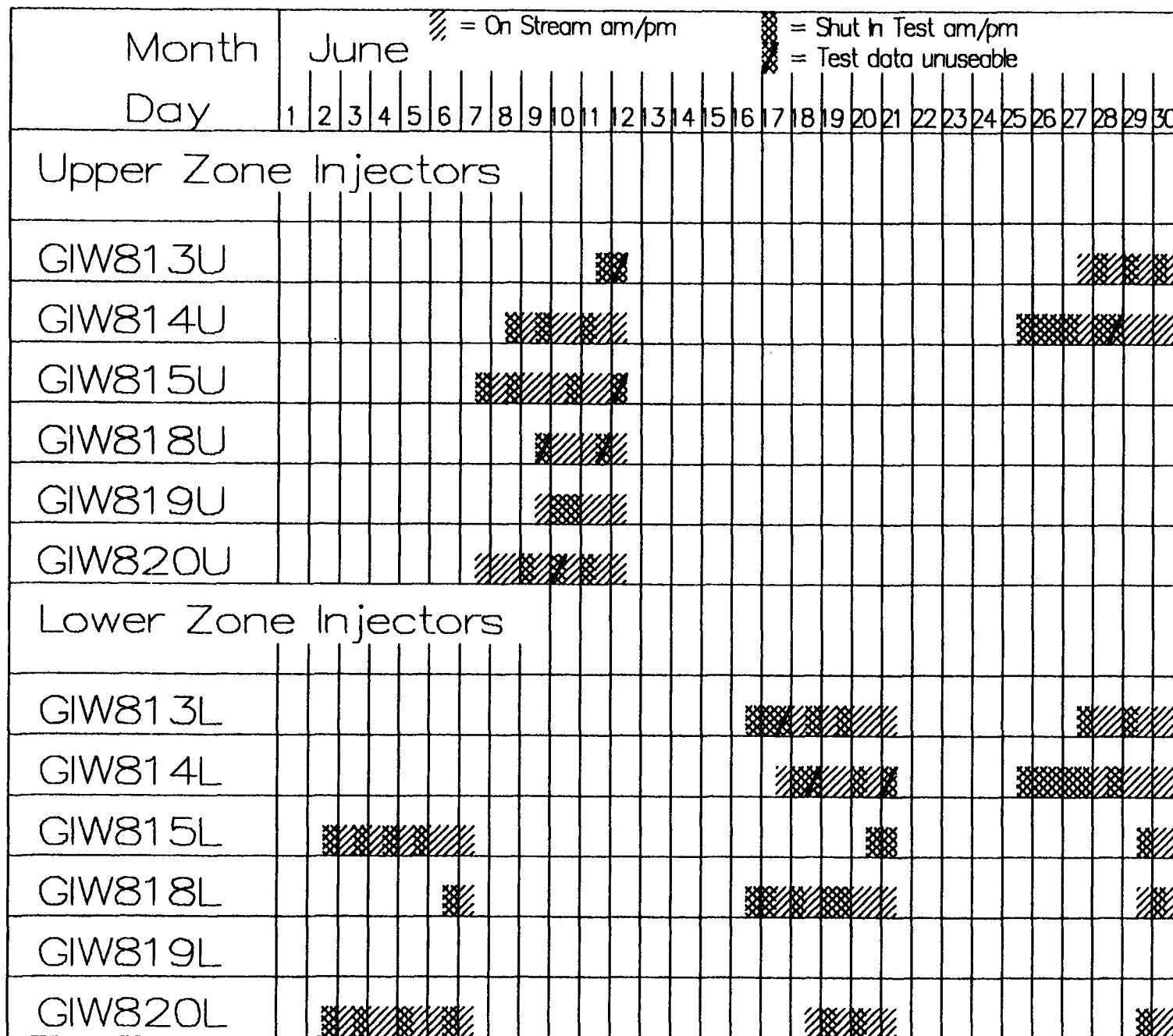


Figure 5

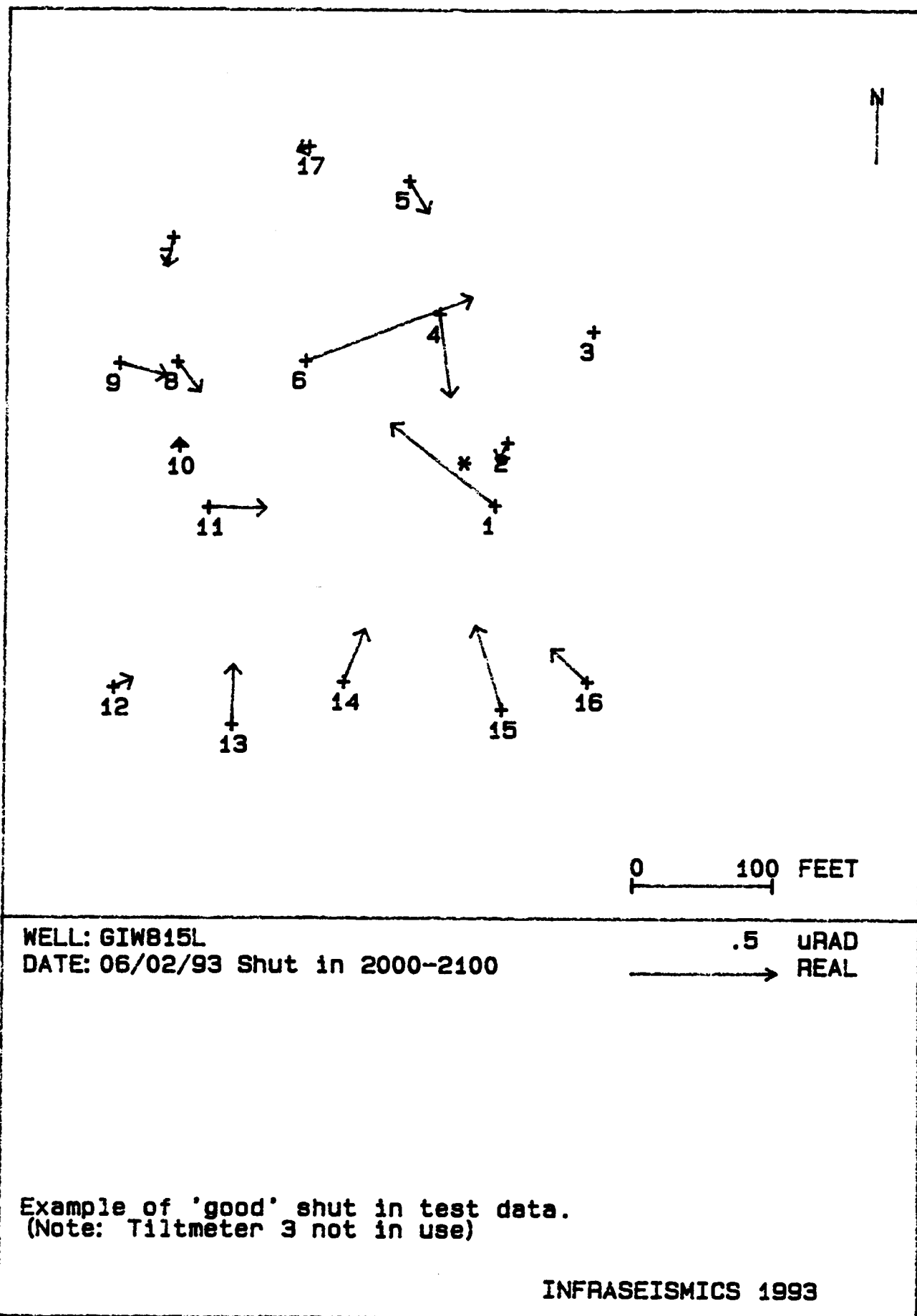
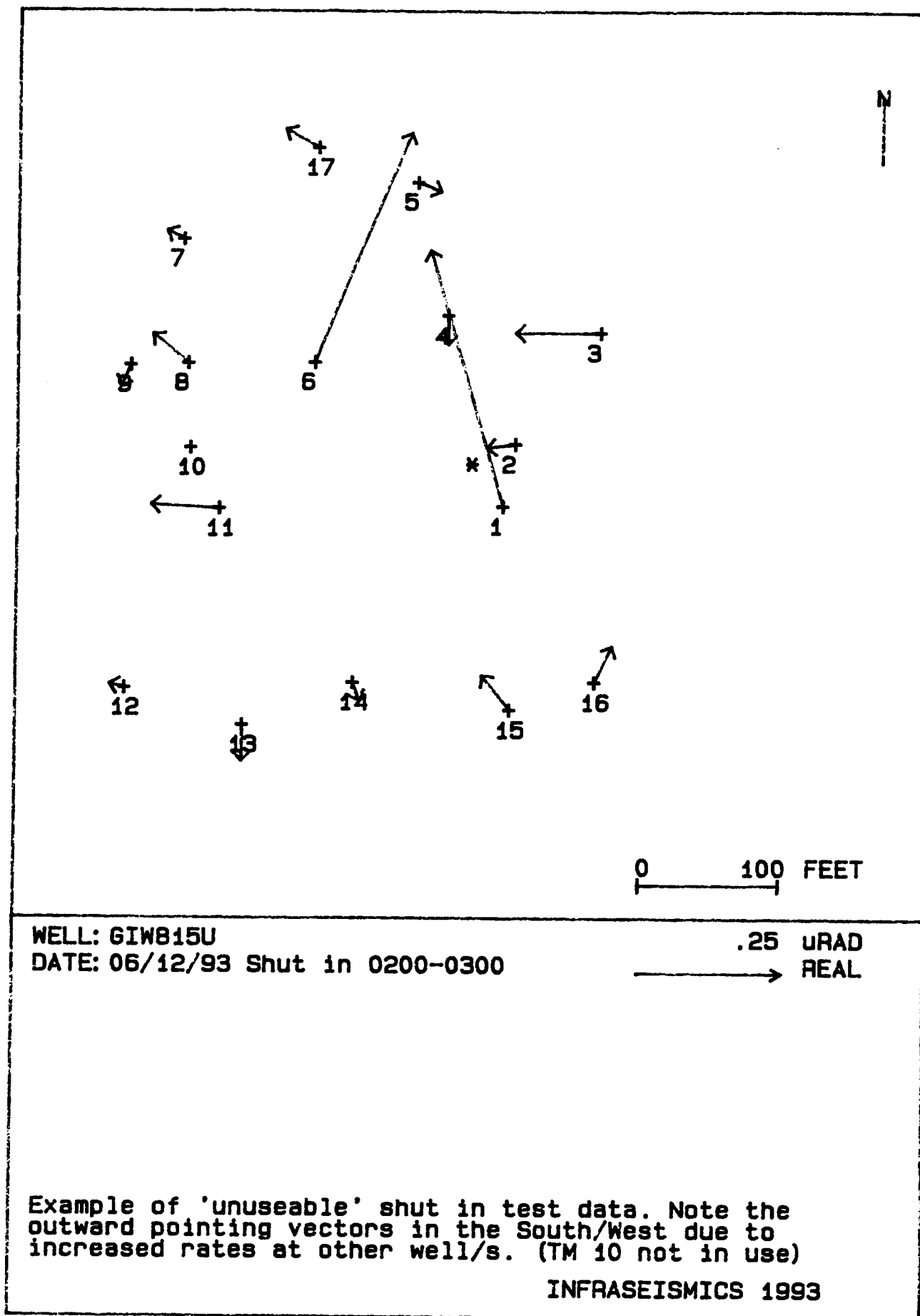
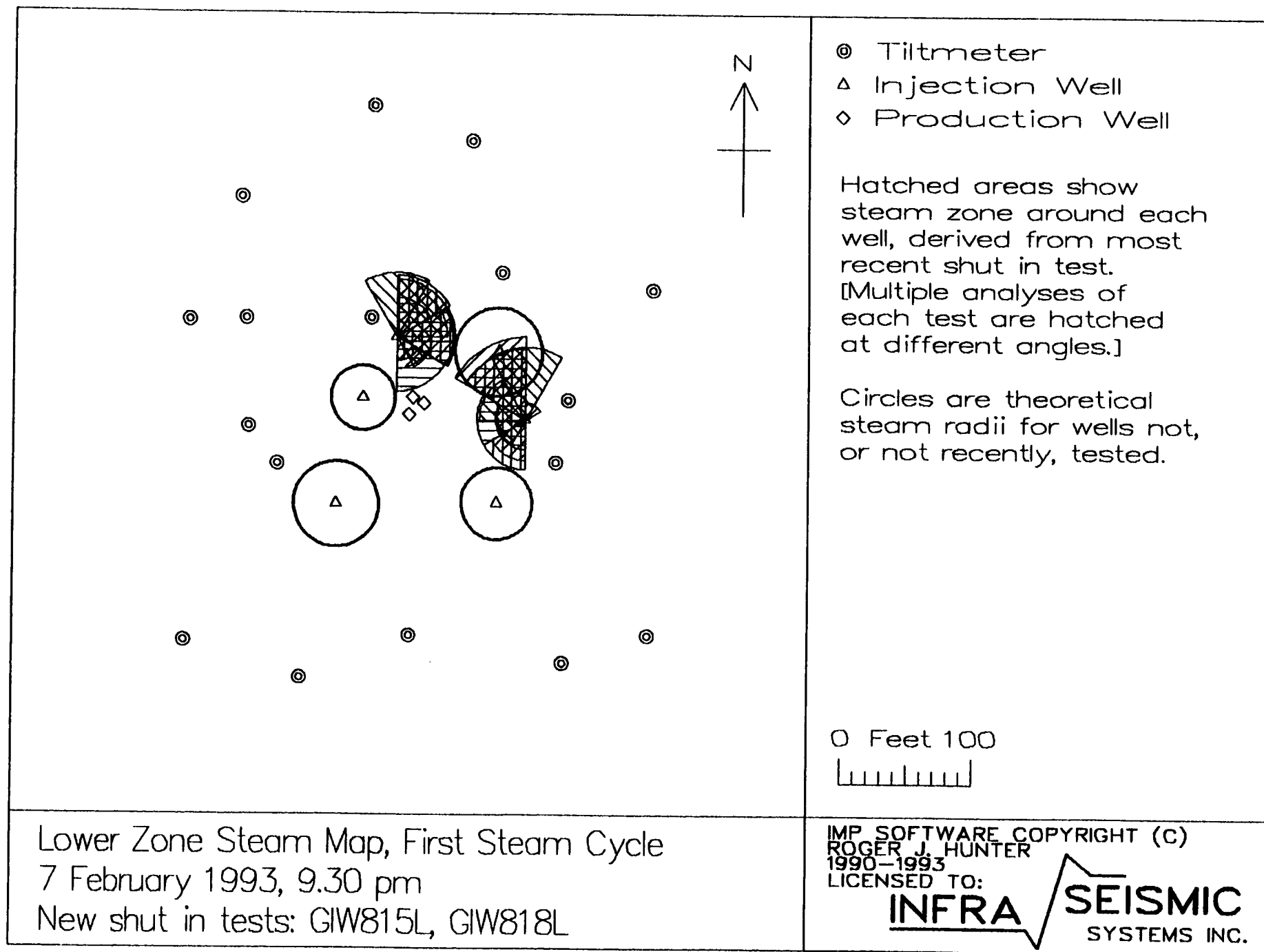
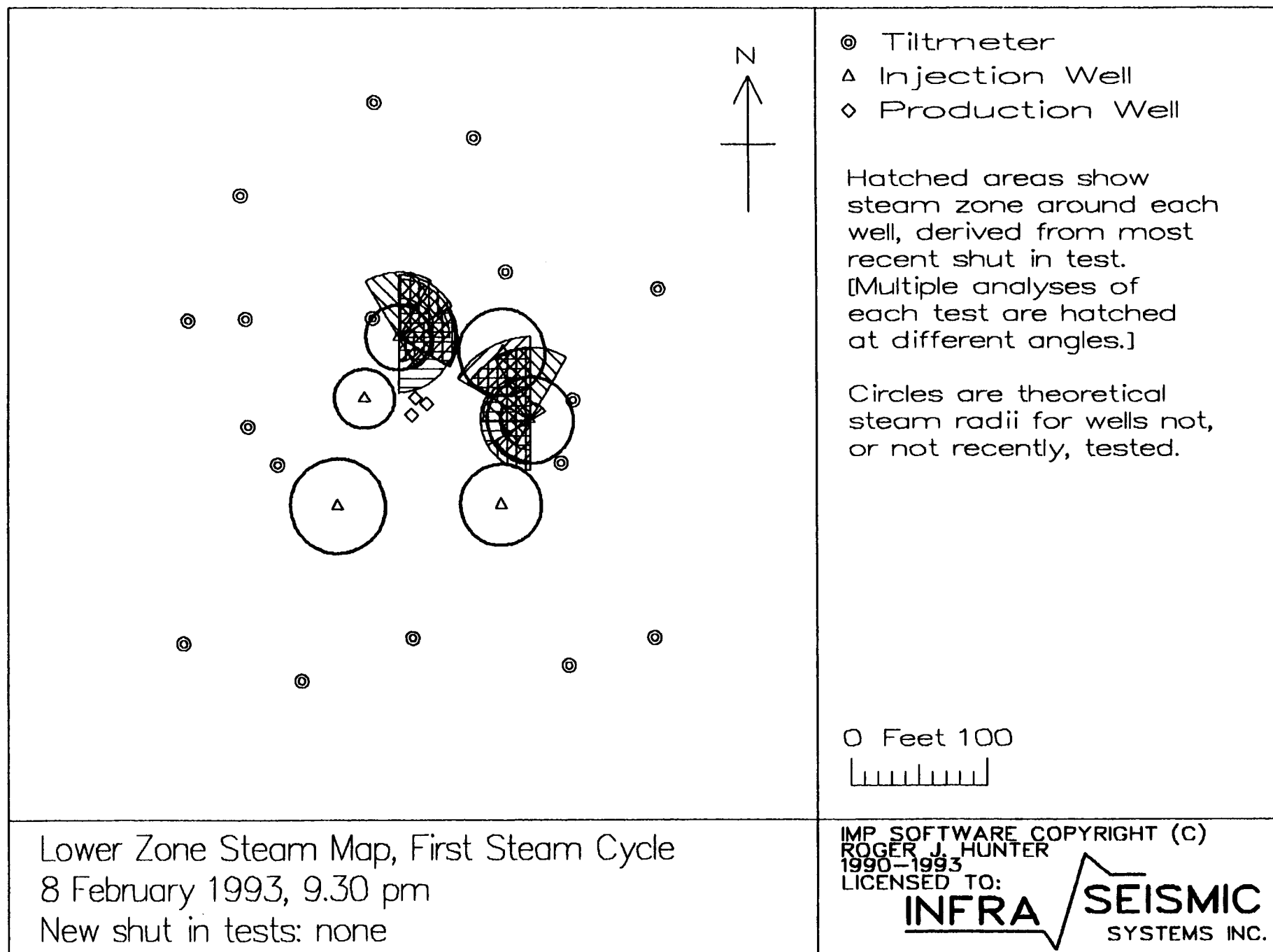
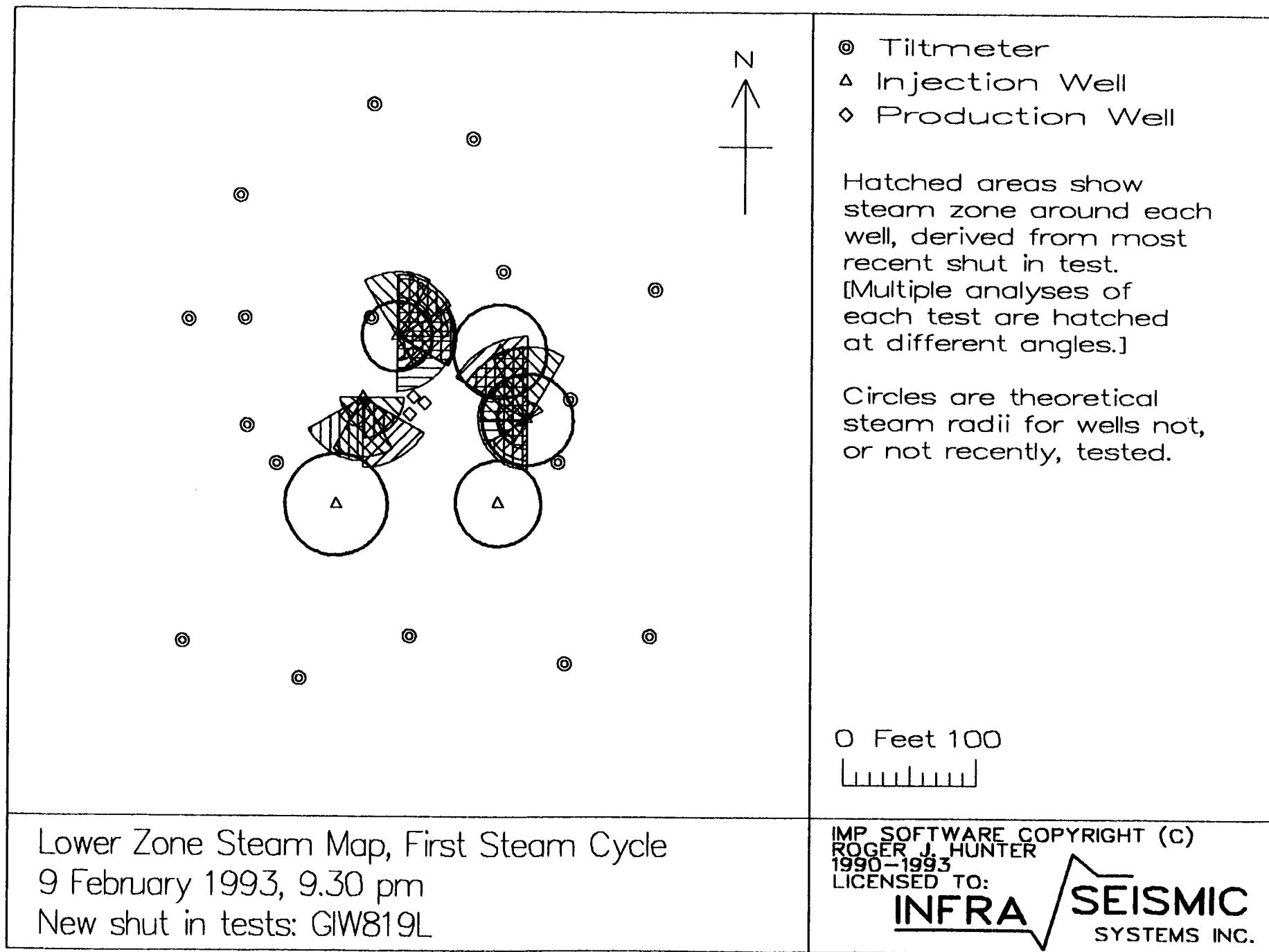


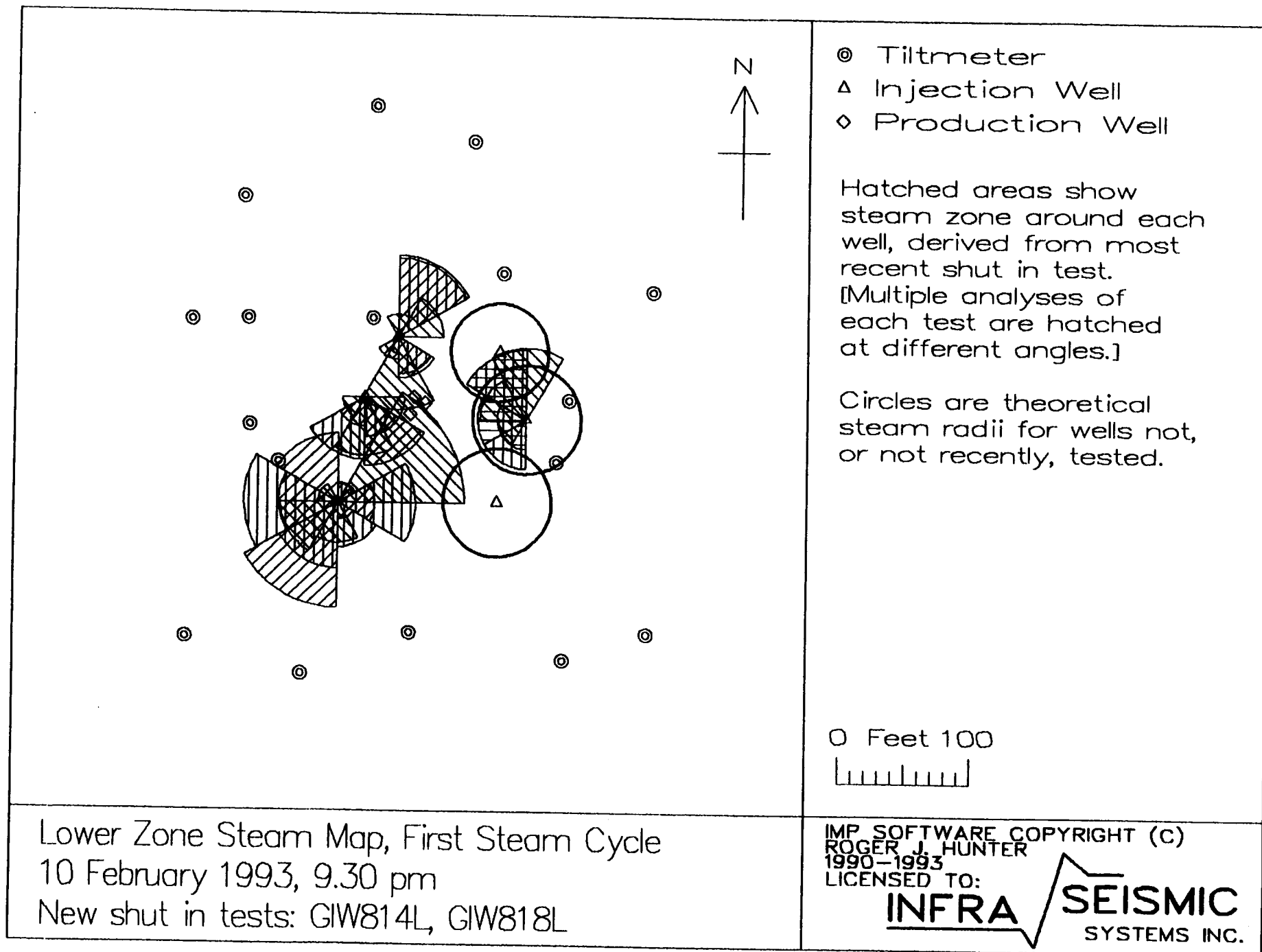
Figure 6

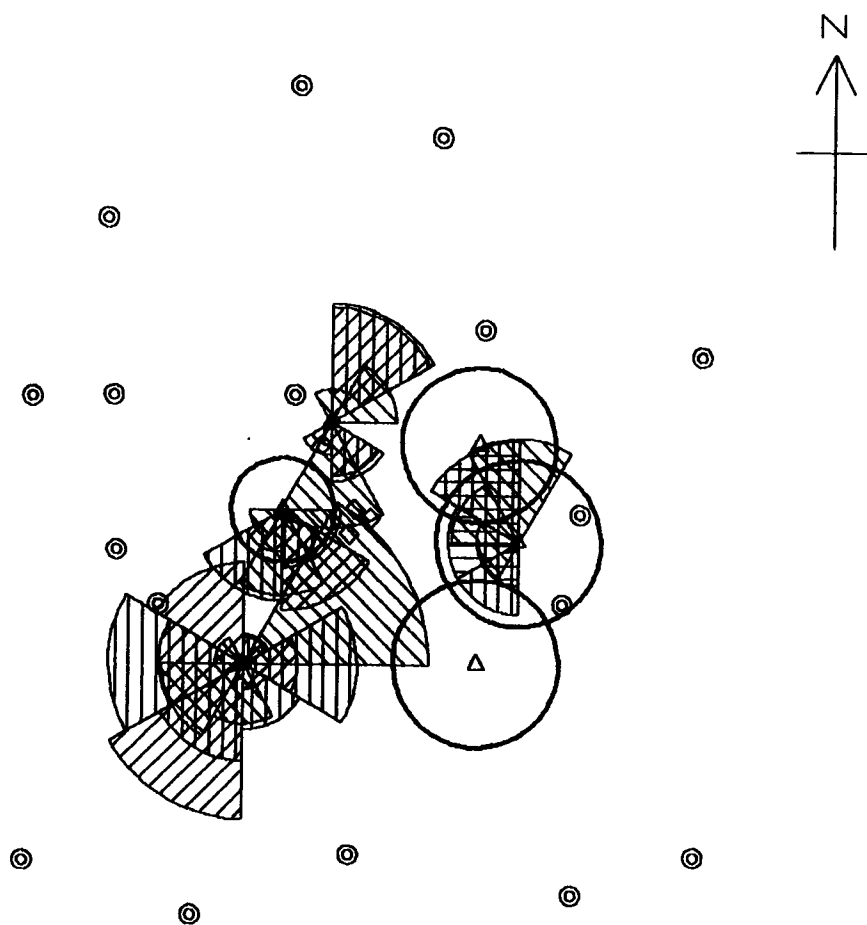












- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test.
[Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

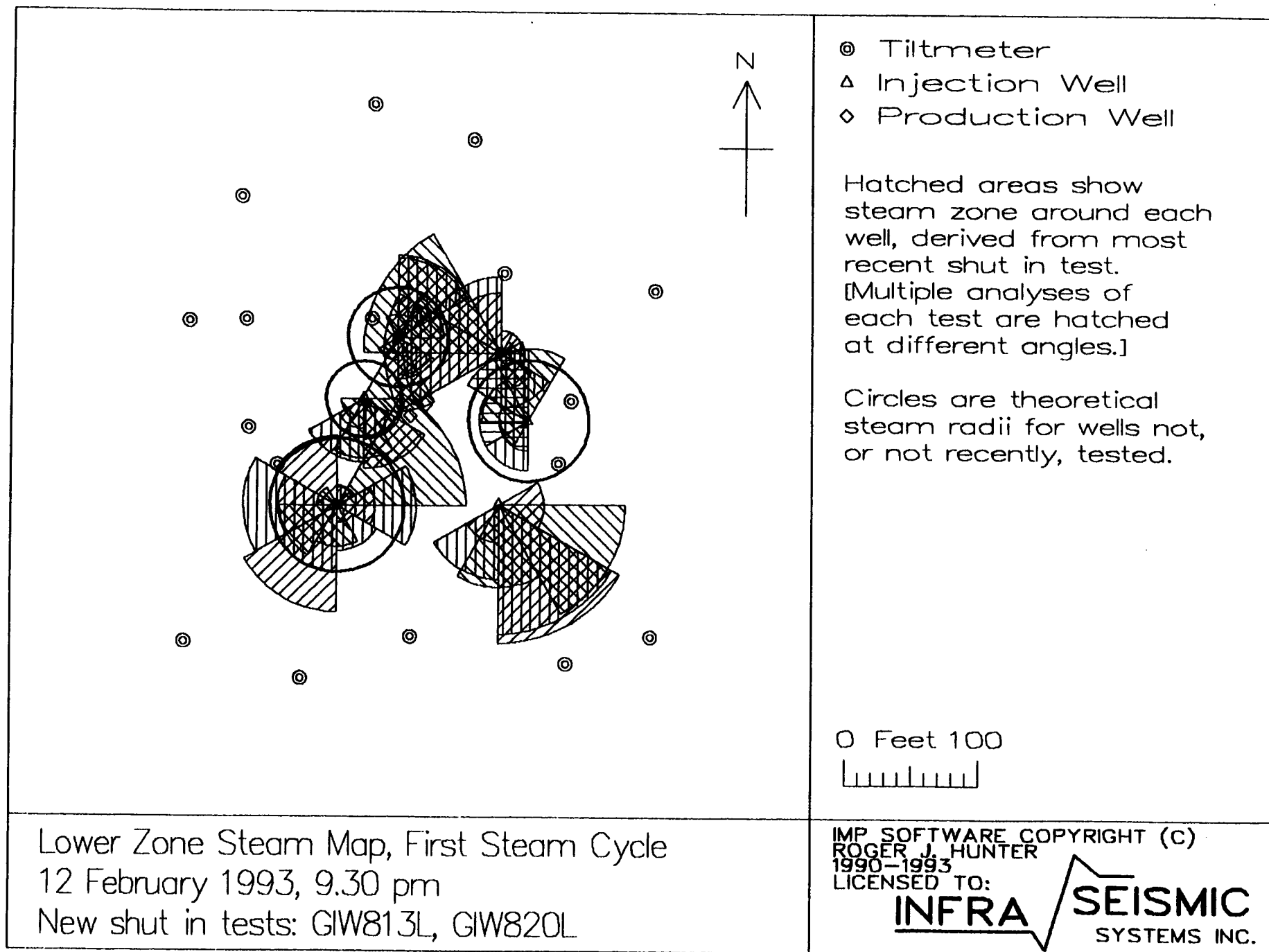
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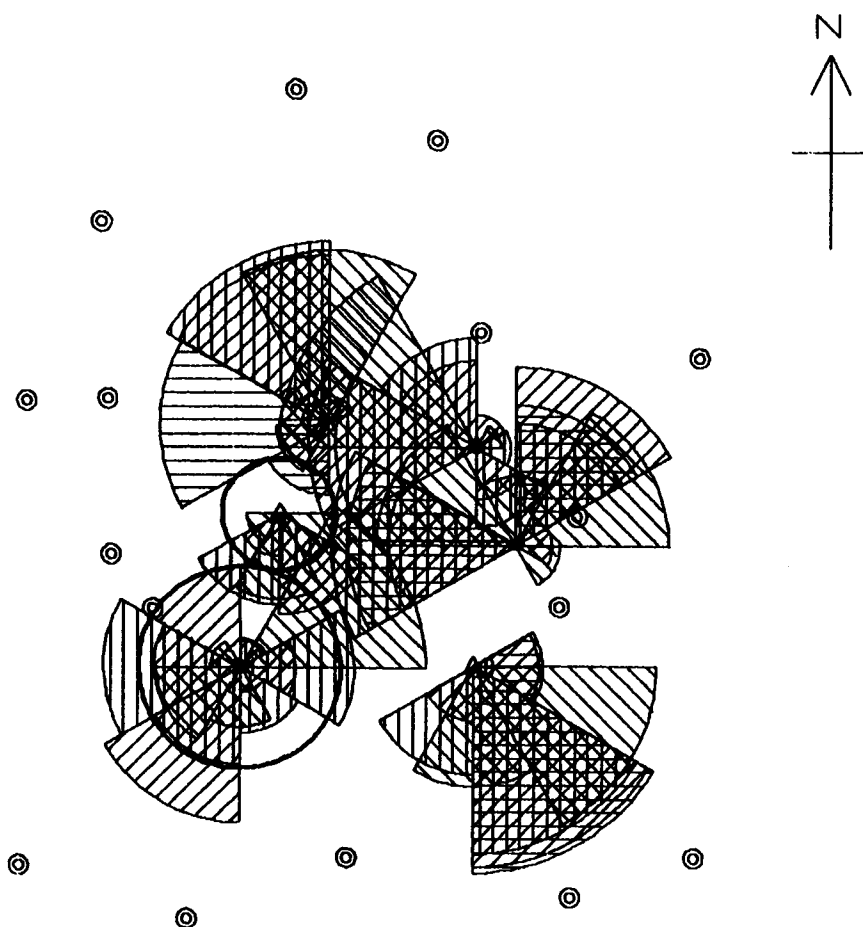


Lower Zone Steam Map, First Steam Cycle
11 February 1993, 9.30 pm
New shut in tests: none

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

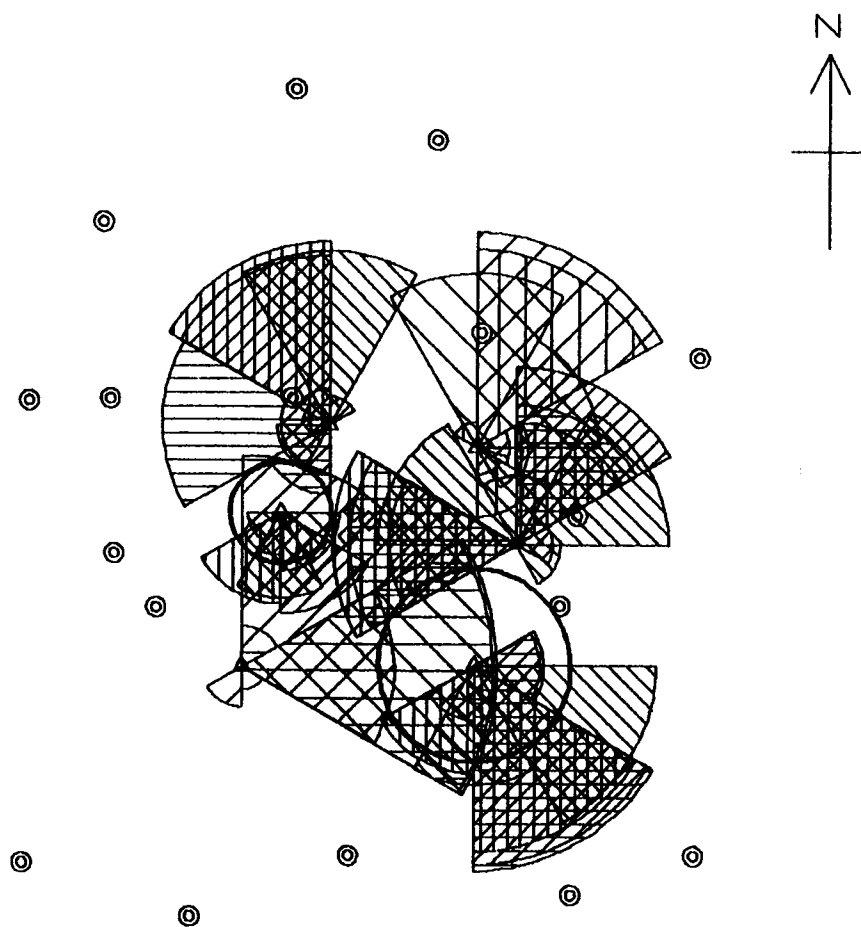
Circles are theoretical steam radii for wells not, or not recently, tested.

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Lower Zone Steam Map, First Steam Cycle
 13 February 1993, 9.30 pm
 New shut in tests: GIW815L, GIW818L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW814L, GIW820L test data quality poor.

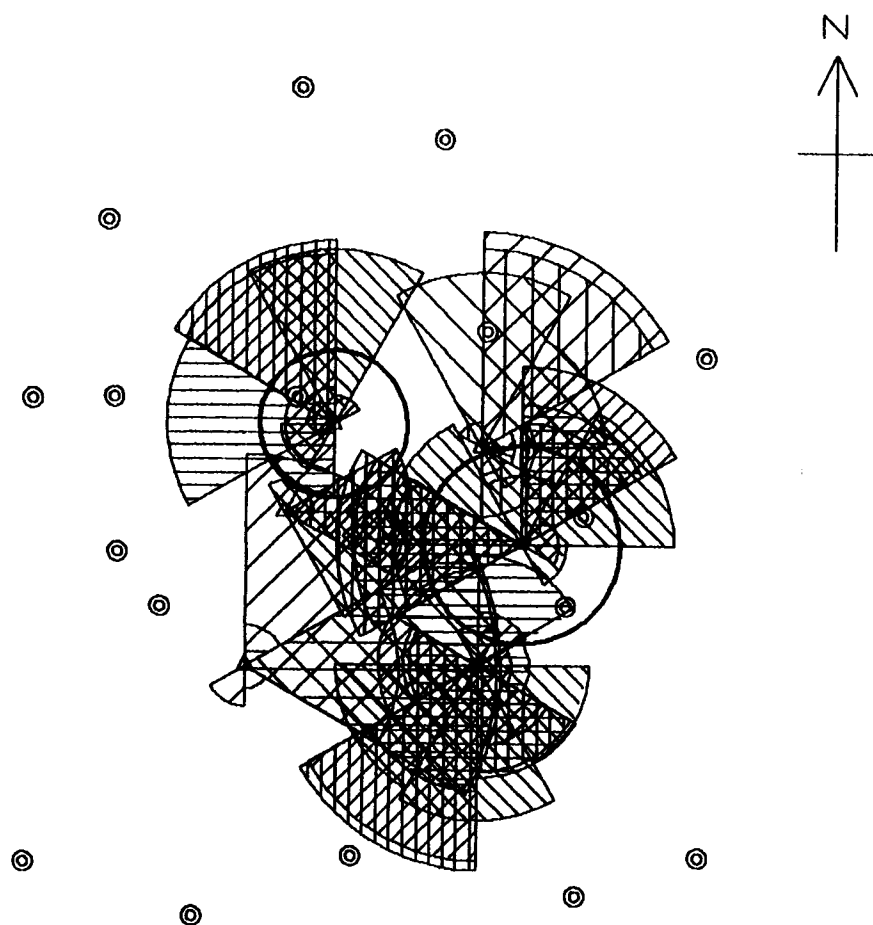
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Lower Zone Steam Map, First Steam Cycle
14 February 1993, 9.30 pm
New shut in tests: GIW814L, GIW820L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

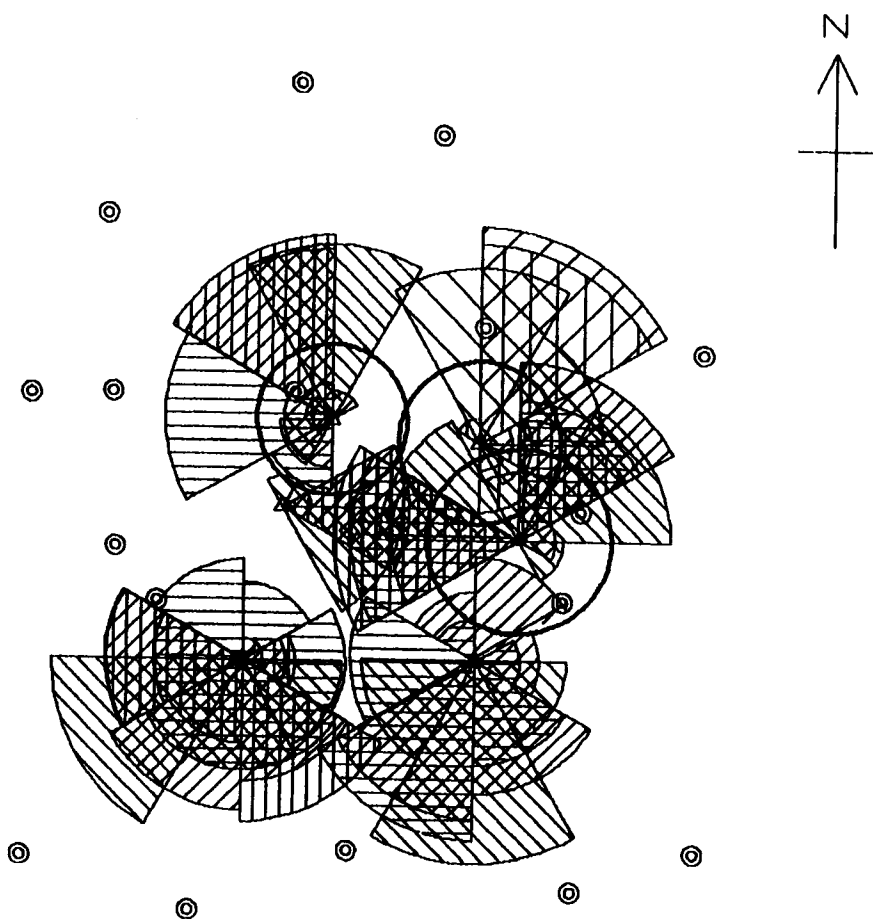
Note: GIW814L, GIW820L test data quality poor.

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Lower Zone Steam Map, First Steam Cycle
 15 February 1993, 9.30 pm
 New shut in tests: GIW813L, GIW819L

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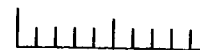
- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW820L test data quality poor.

0 Feet 100

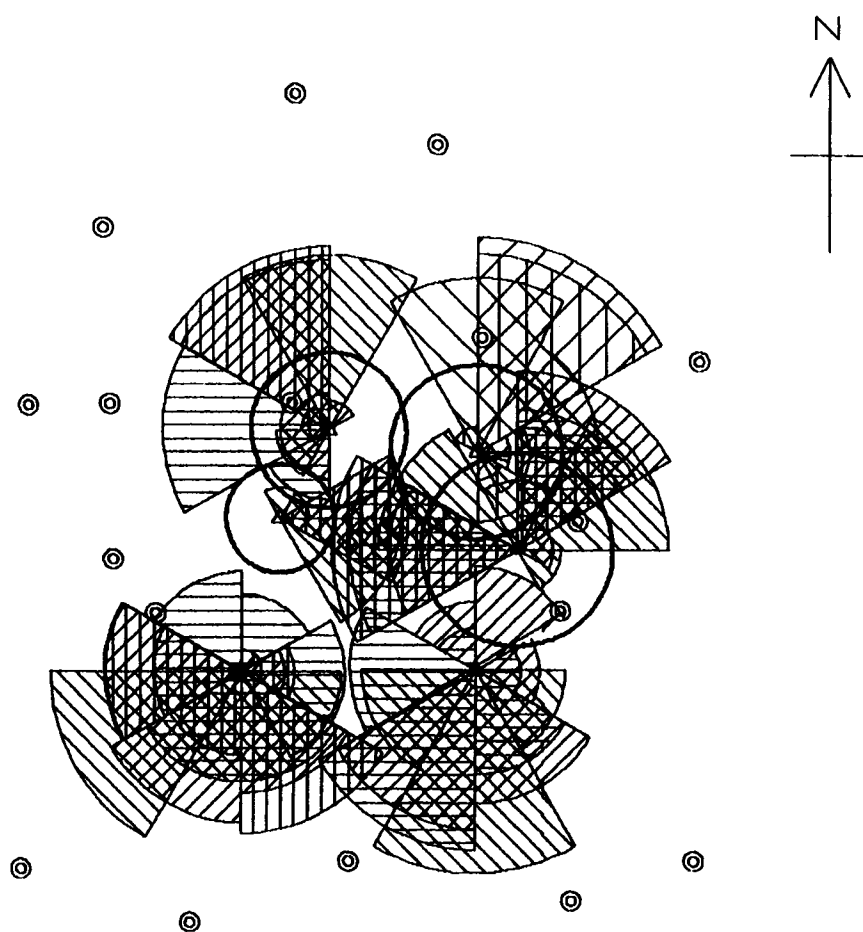


Lower Zone Steam Map, First Steam Cycle
16 February 1993, 9.30 pm
New shut in tests: GIW813L, GIW814L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW820L test data quality poor.

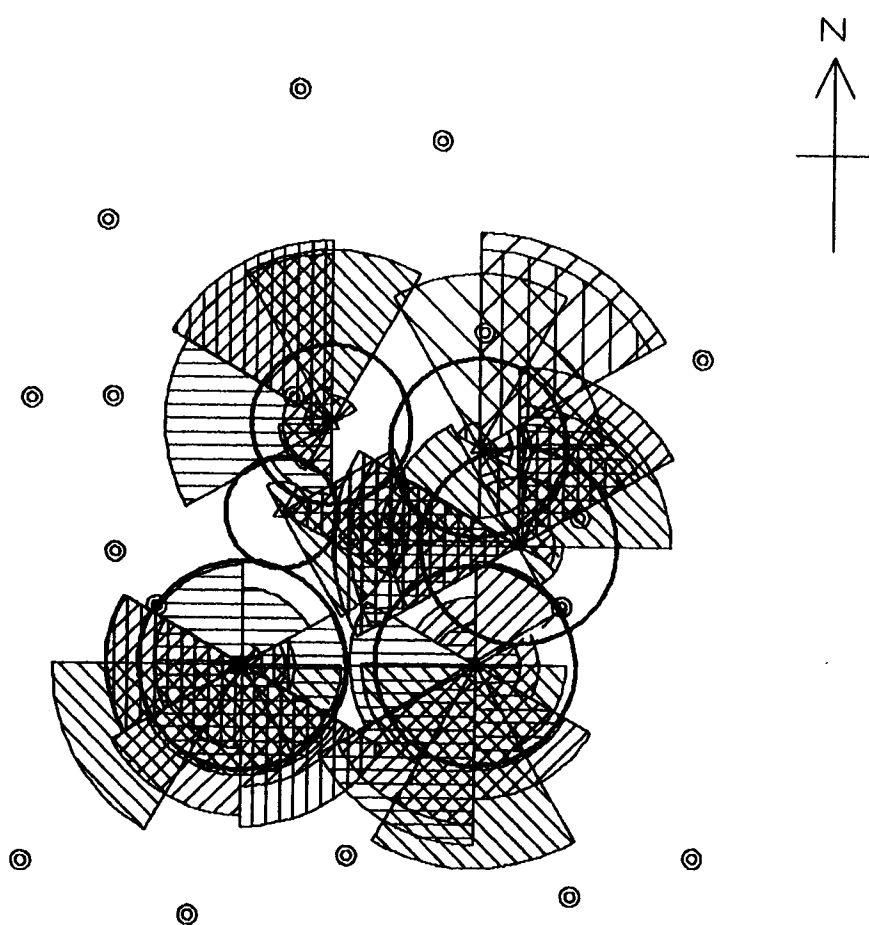
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Lower Zone Steam Map, First Steam Cycle
17 February 1993, 9.30 pm
New shut in tests: none

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW820L test data quality poor.

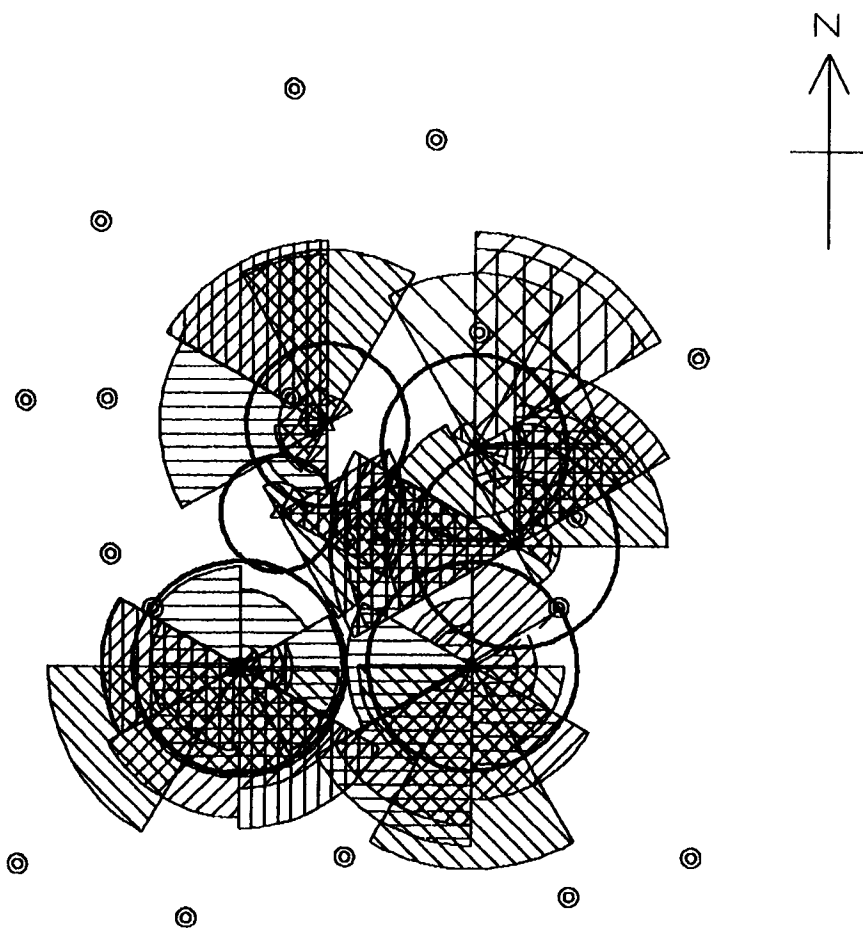
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Lower Zone Steam Map, First Steam Cycle
18 February 1993, 9.30 pm
New shut in tests: none

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Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW820L test data quality poor.

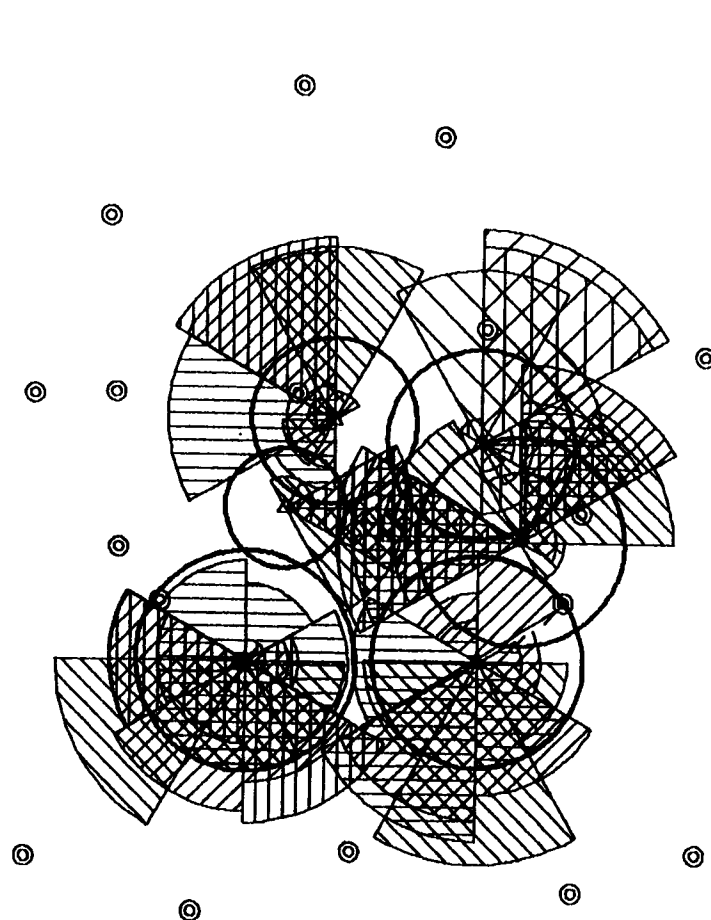
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Lower Zone Steam Map, First Steam Cycle
19 February 1993, 9.30 pm
New shut in tests: none

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Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW820L test data quality poor.

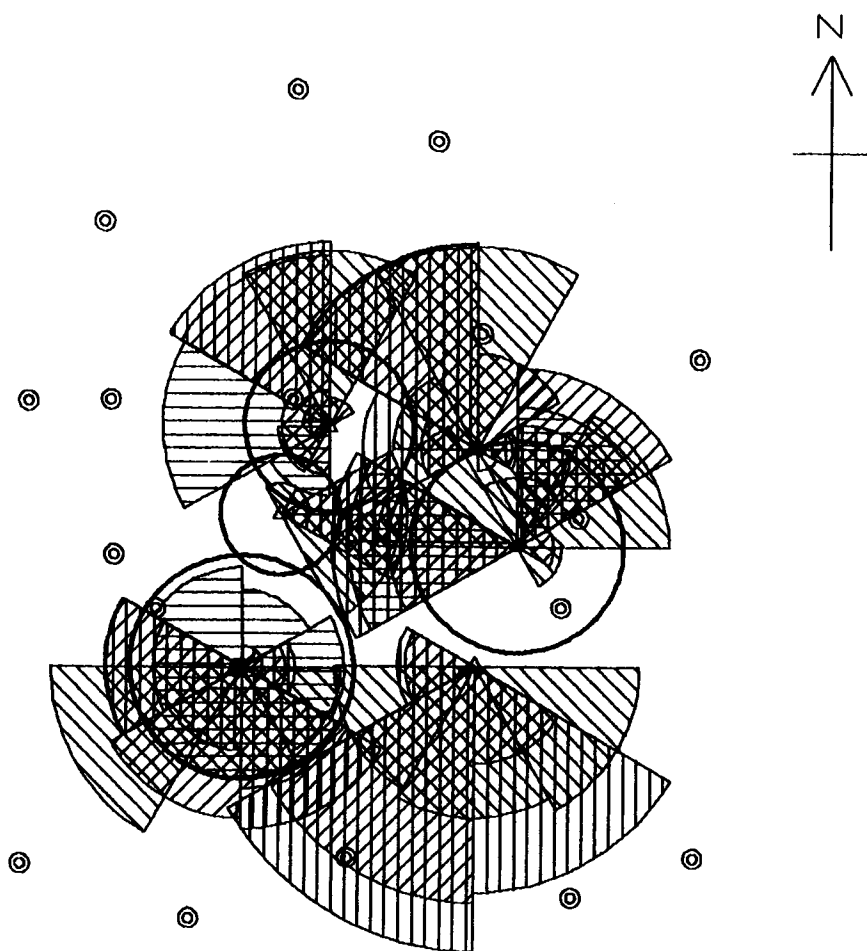
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Lower Zone Steam Map, First Steam Cycle
20 February 1993, 9.30 pm
New shut in tests: none

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- ⊙ Tiltmeter
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- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

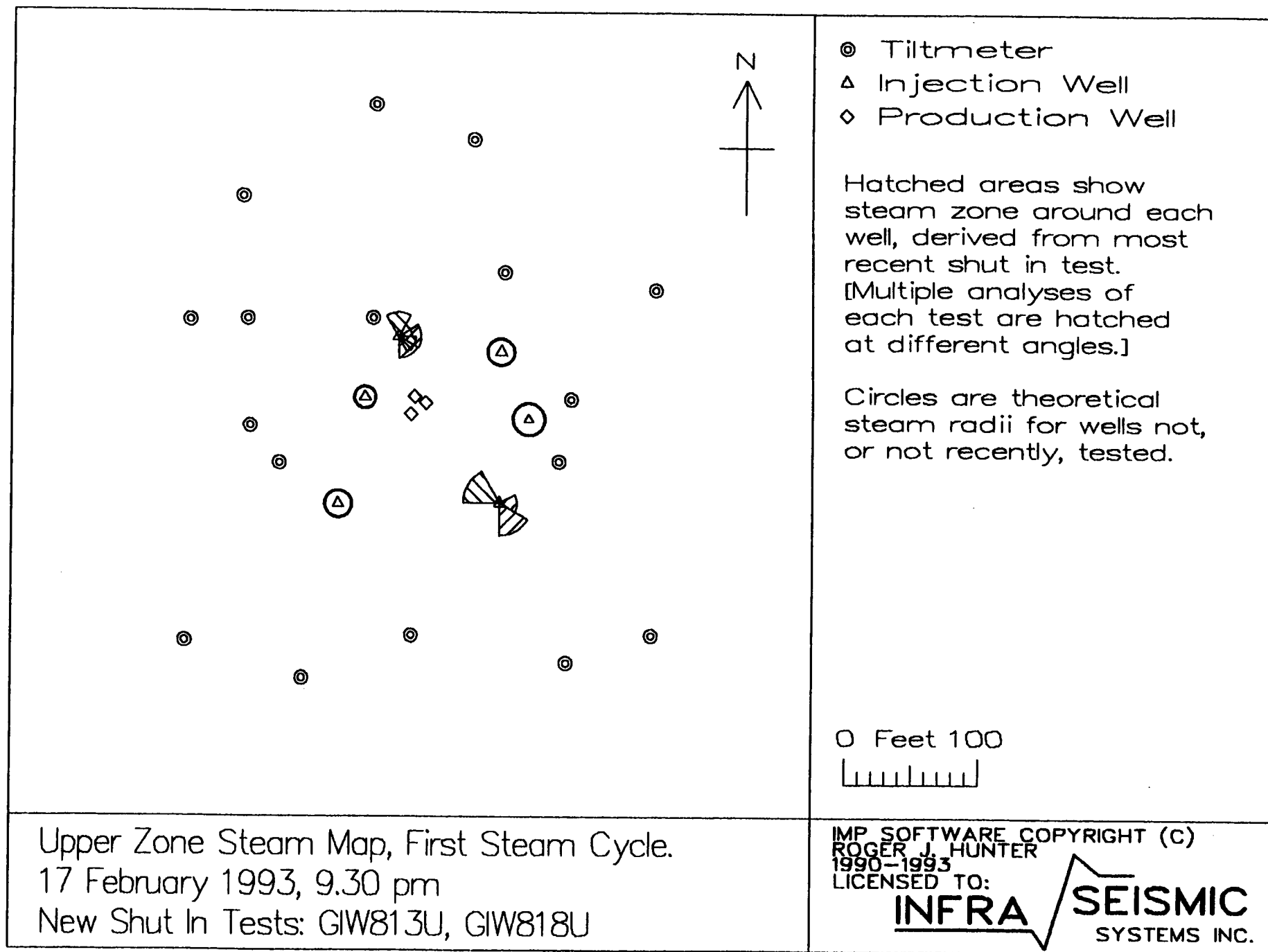
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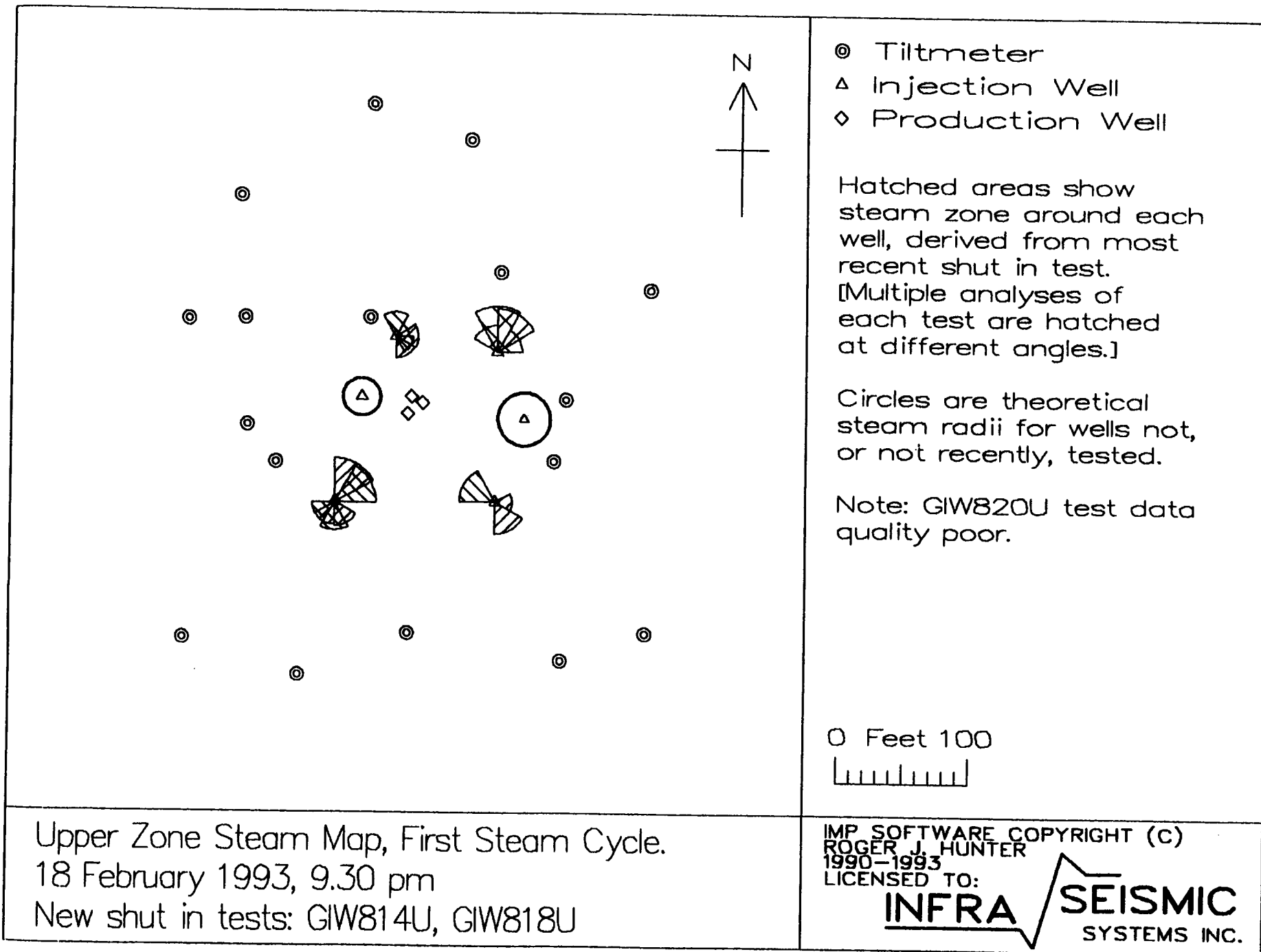


Lower Zone Steam Map, First Steam Cycle
21 February 1993, 9.30 pm
New shut in tests: GIW813L, GIW820L

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- ⊙ Tiltmeter
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- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW815U, GIW820U data quality poor

0 Feet 100



Upper Zone Steam Map, First Steam Cycle.
19 February 1993, 9.30 pm
New shut in tests: GIW815U, GIW819U

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW815U, GIW820U data quality poor

0 Feet 100

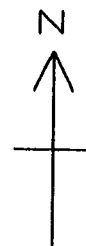


Upper Zone Steam Map, First Steam Cycle.
20 February 1993, 9.30 pm
New shut in tests: GIW813U, GIW818U

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test.
[Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW815U, GIW820U data quality poor

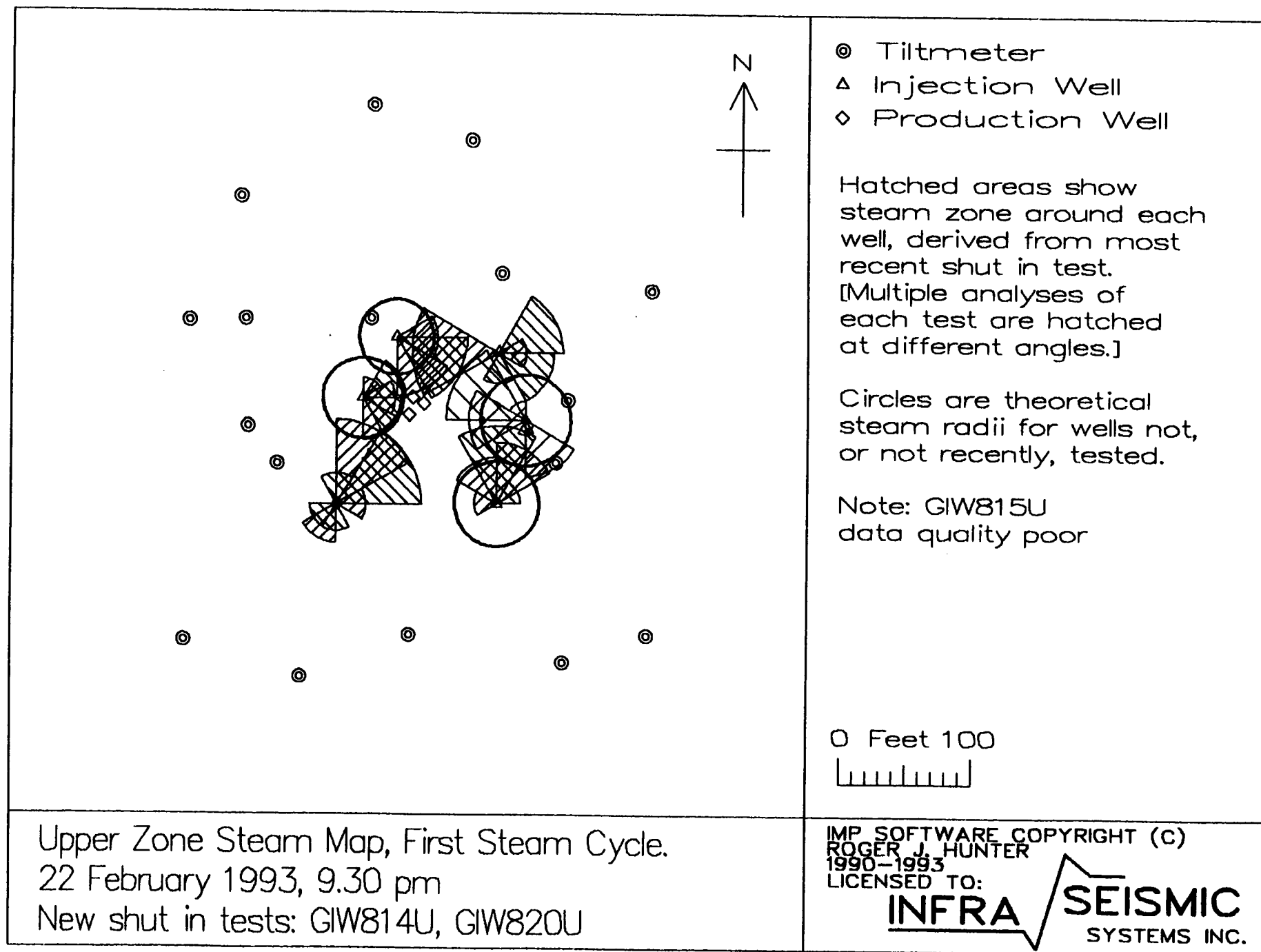
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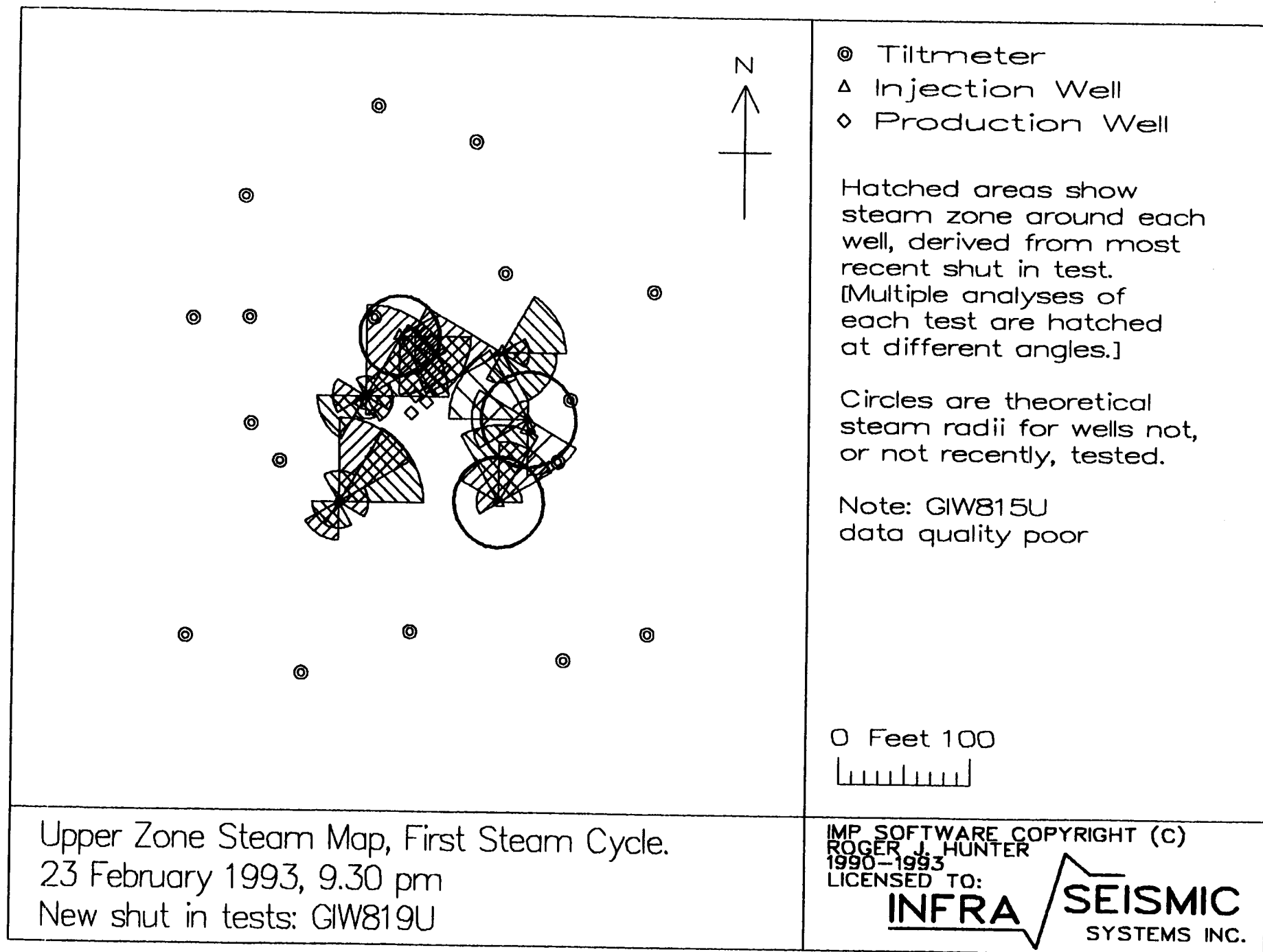


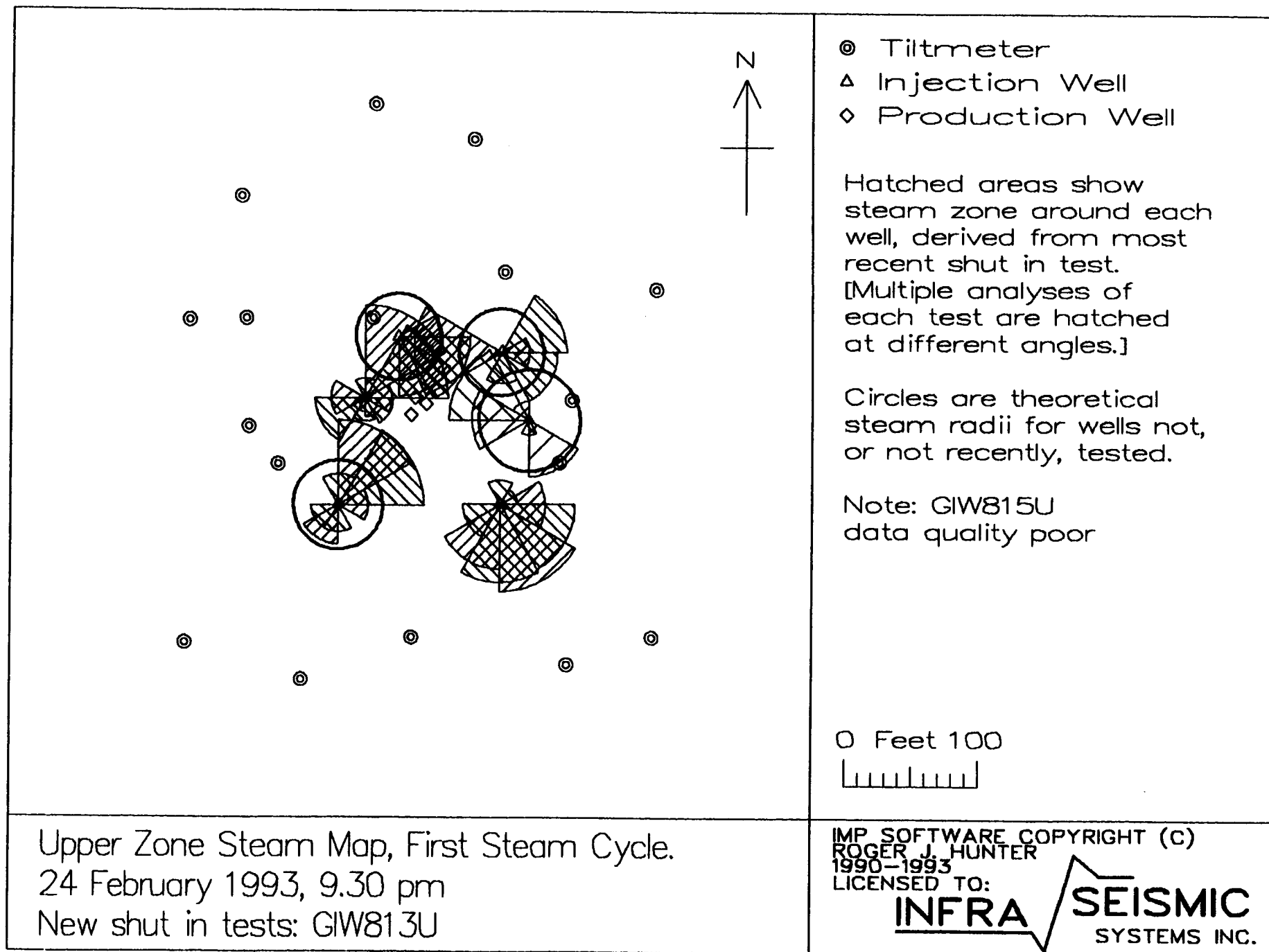
Upper Zone Steam Map, First Steam Cycle.
21 February 1993, 9.30 pm
New shut in tests: none

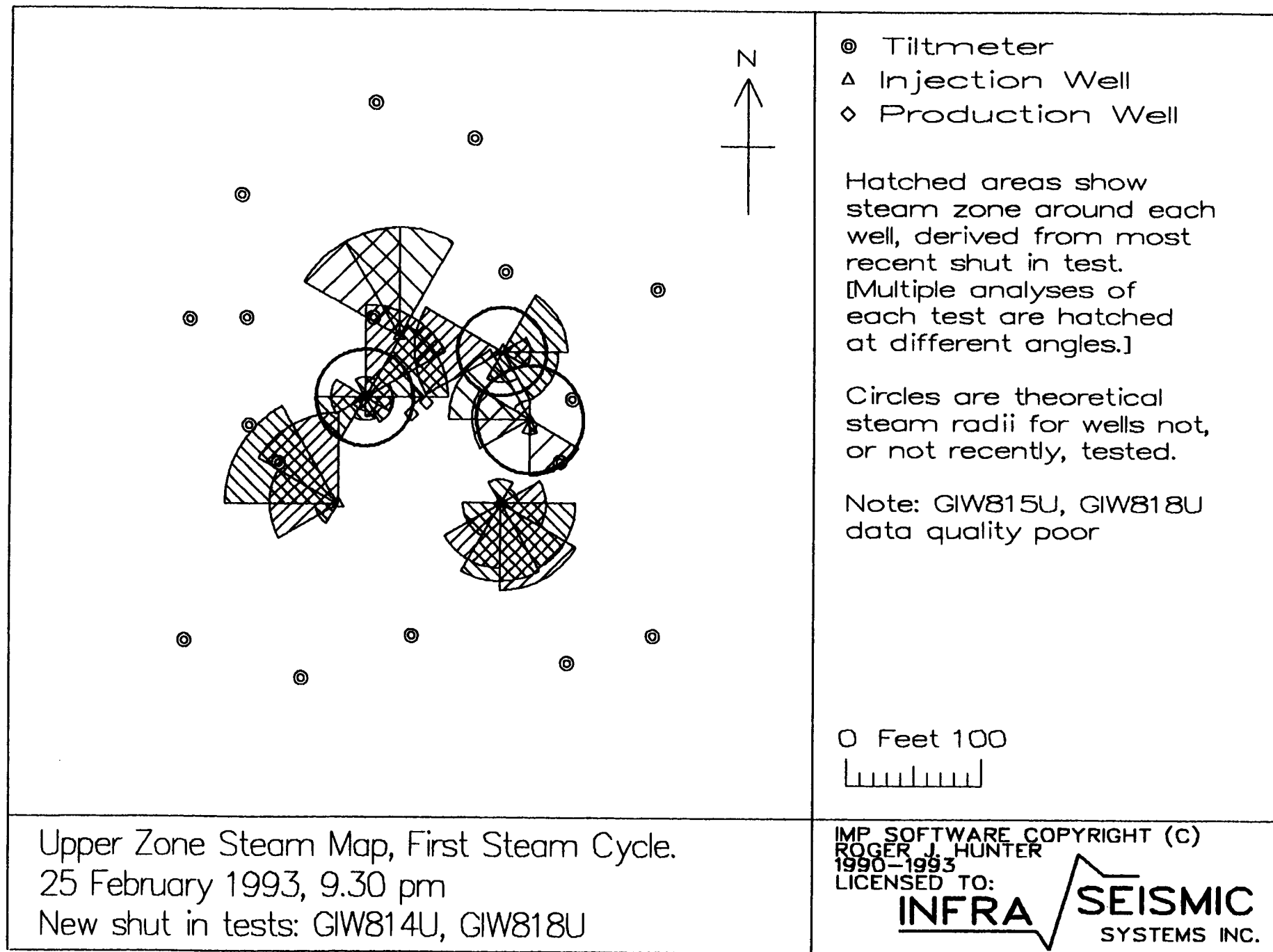
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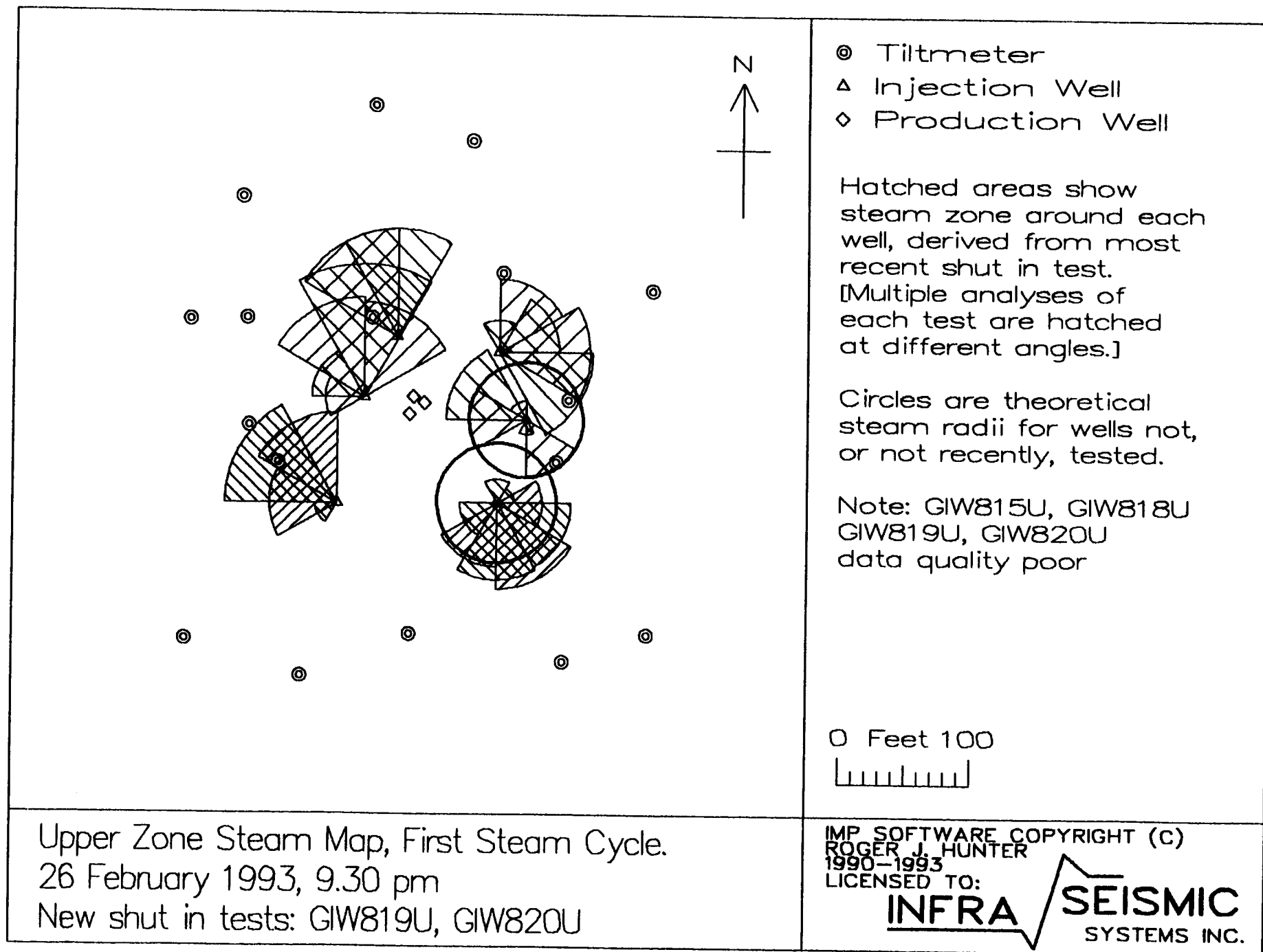
INFRA **SEISMIC**
SYSTEMS INC.

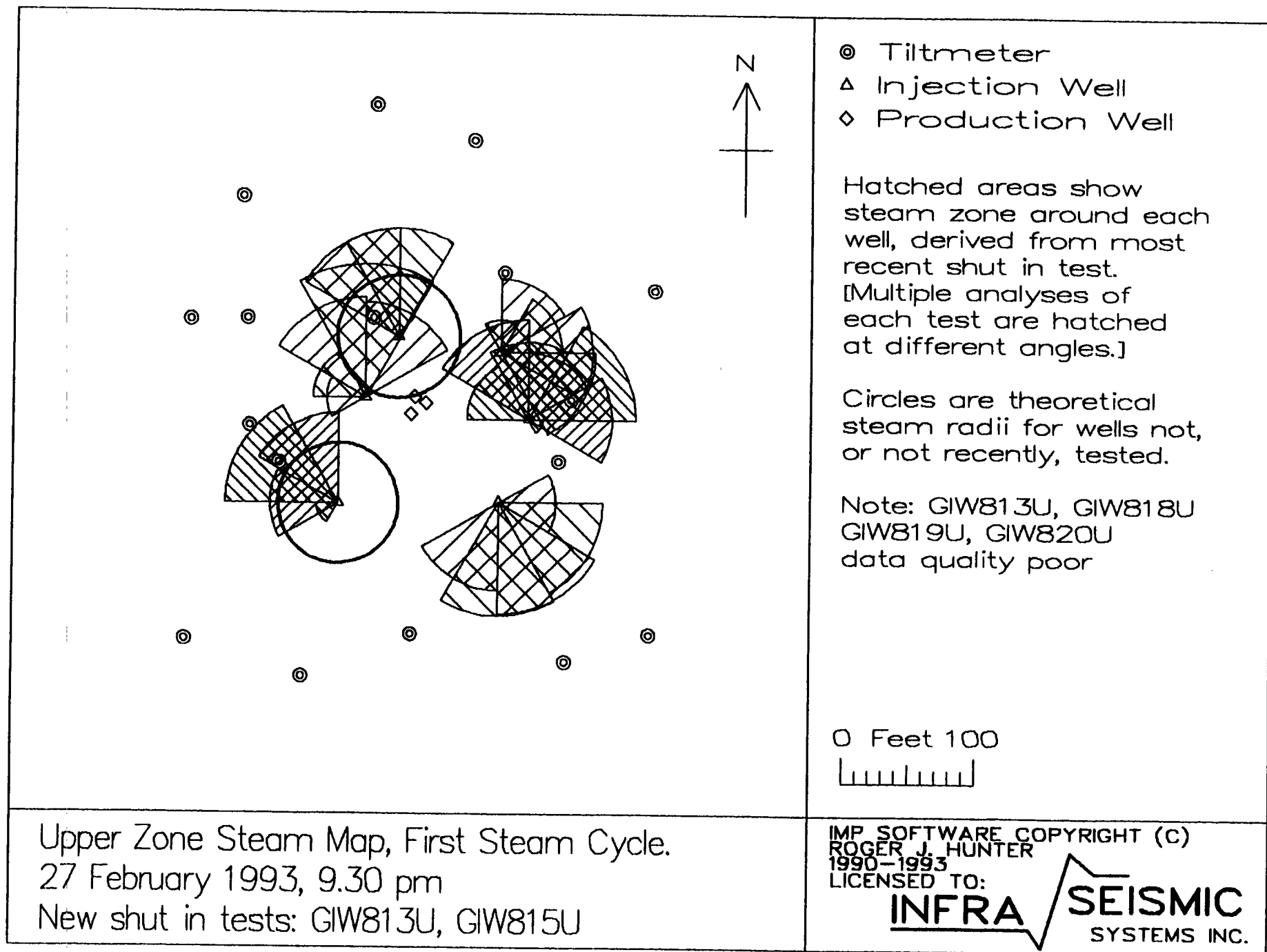


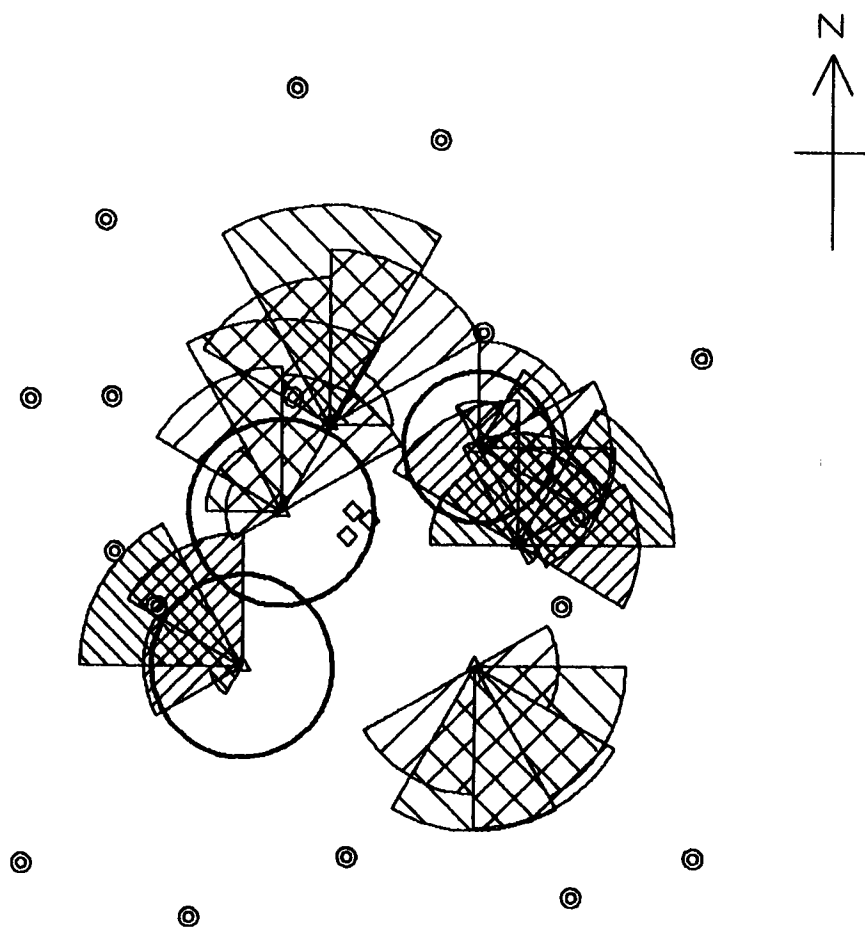












- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW813U, GIW818U
GIW819U, GIW820U
data quality poor

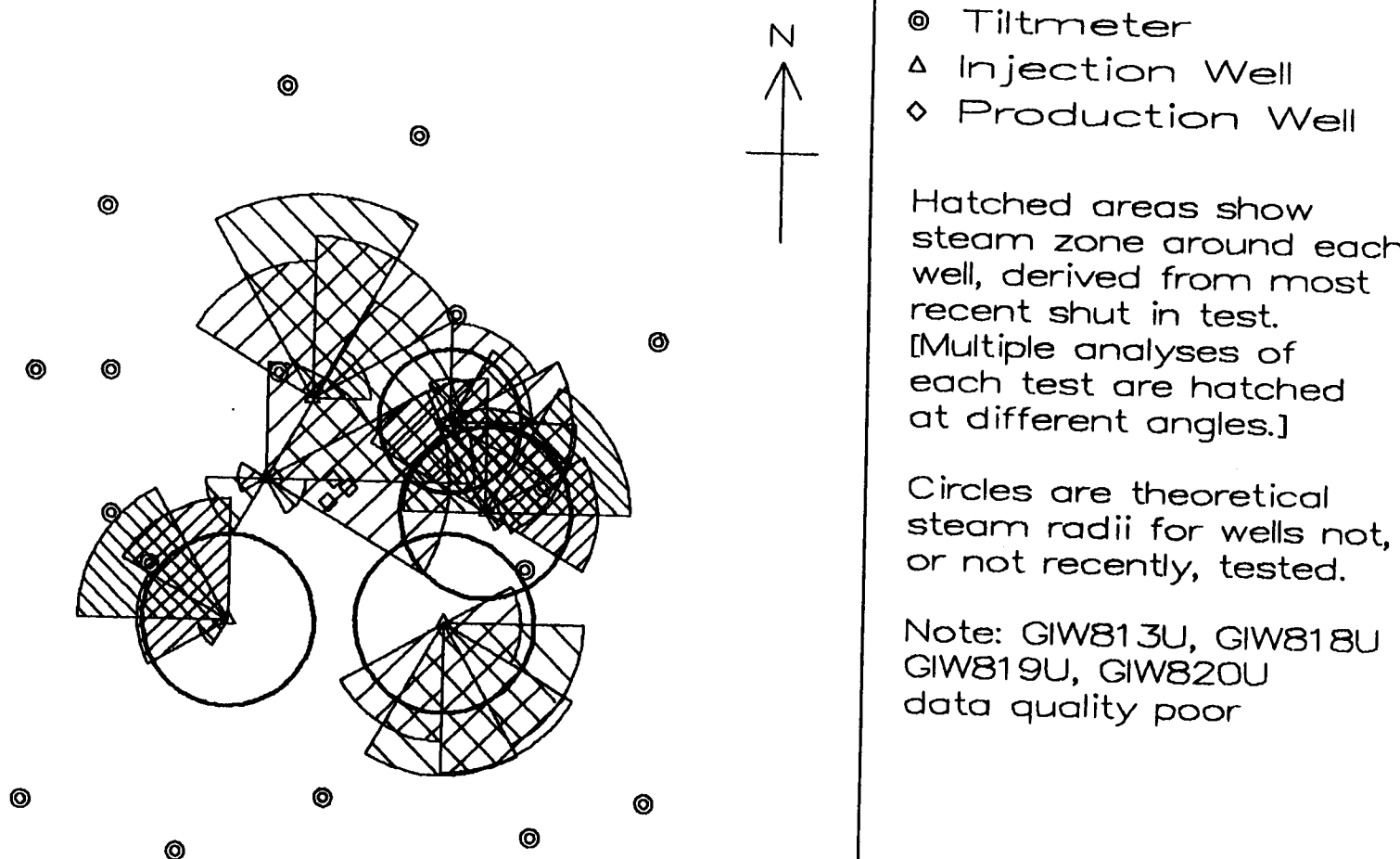
0 Feet 100



Upper Zone Steam Map, First Steam Cycle.
28 February 1993, 9.30 pm
New shut in tests: GIW818U

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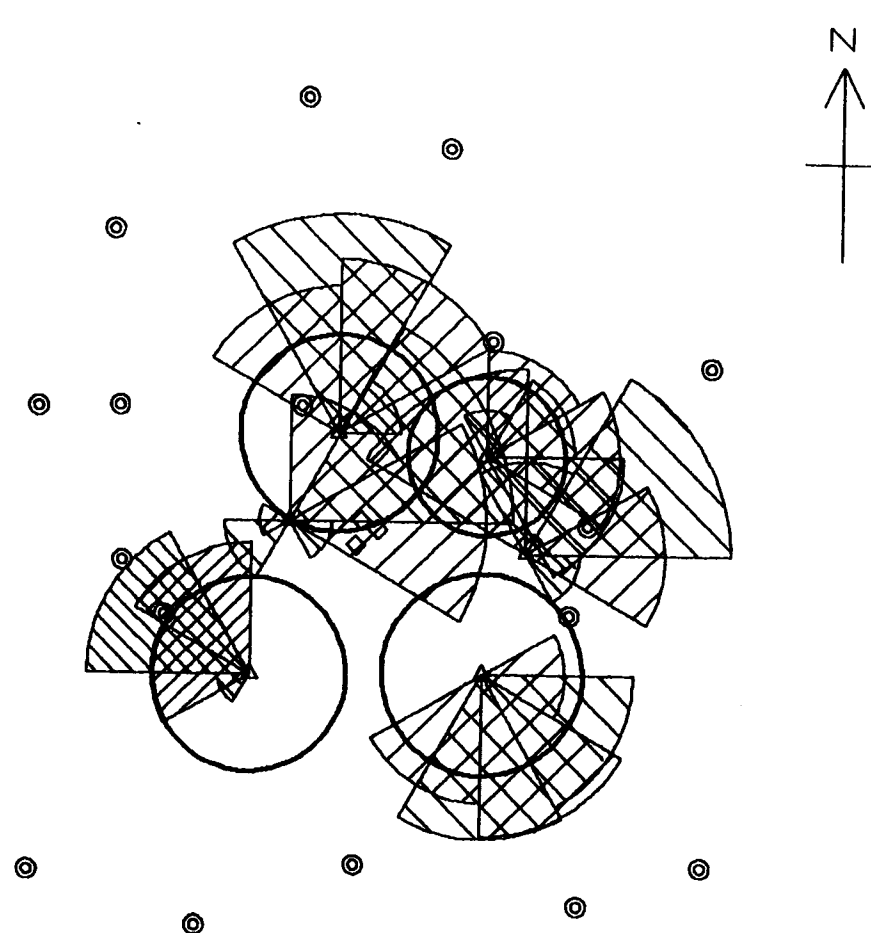
0 Feet 100



Upper Zone Steam Map, First Steam Cycle.
 1 March 1993, 9.30 pm
 New shut in tests: GIW819U

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW813U, GIW815U
GIW818U, GIW819U, GIW820U
data quality poor

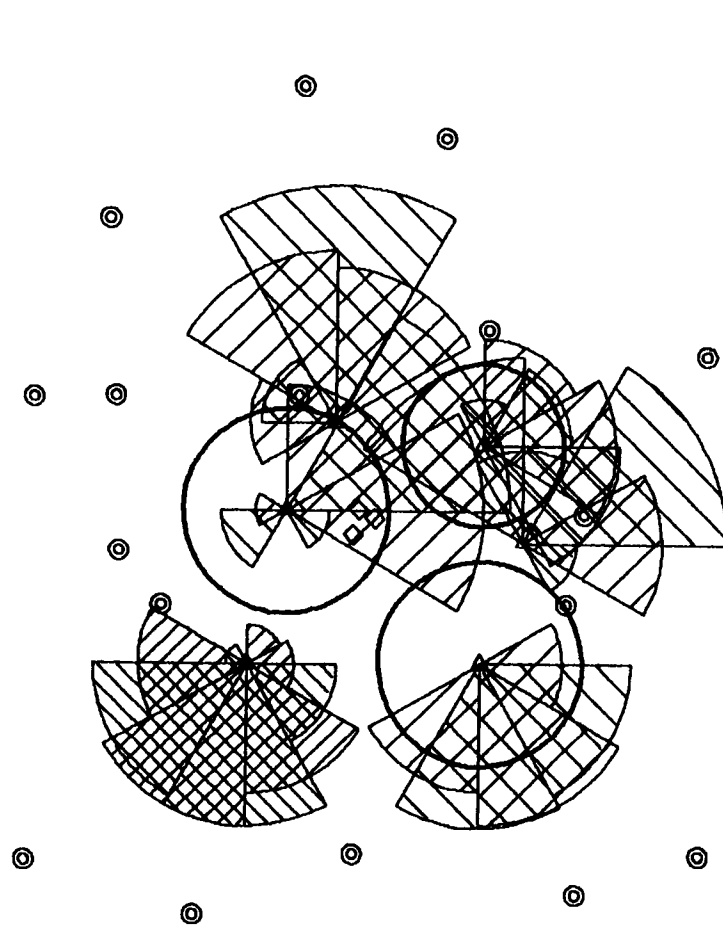
0 Feet 100



Upper Zone Steam Map, First Steam Cycle.
2 March 1993, 9.30 pm
New shut in tests: GIW815U

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW813U, GIW815U
GIW818U, GIW819U, GIW820U
data quality poor

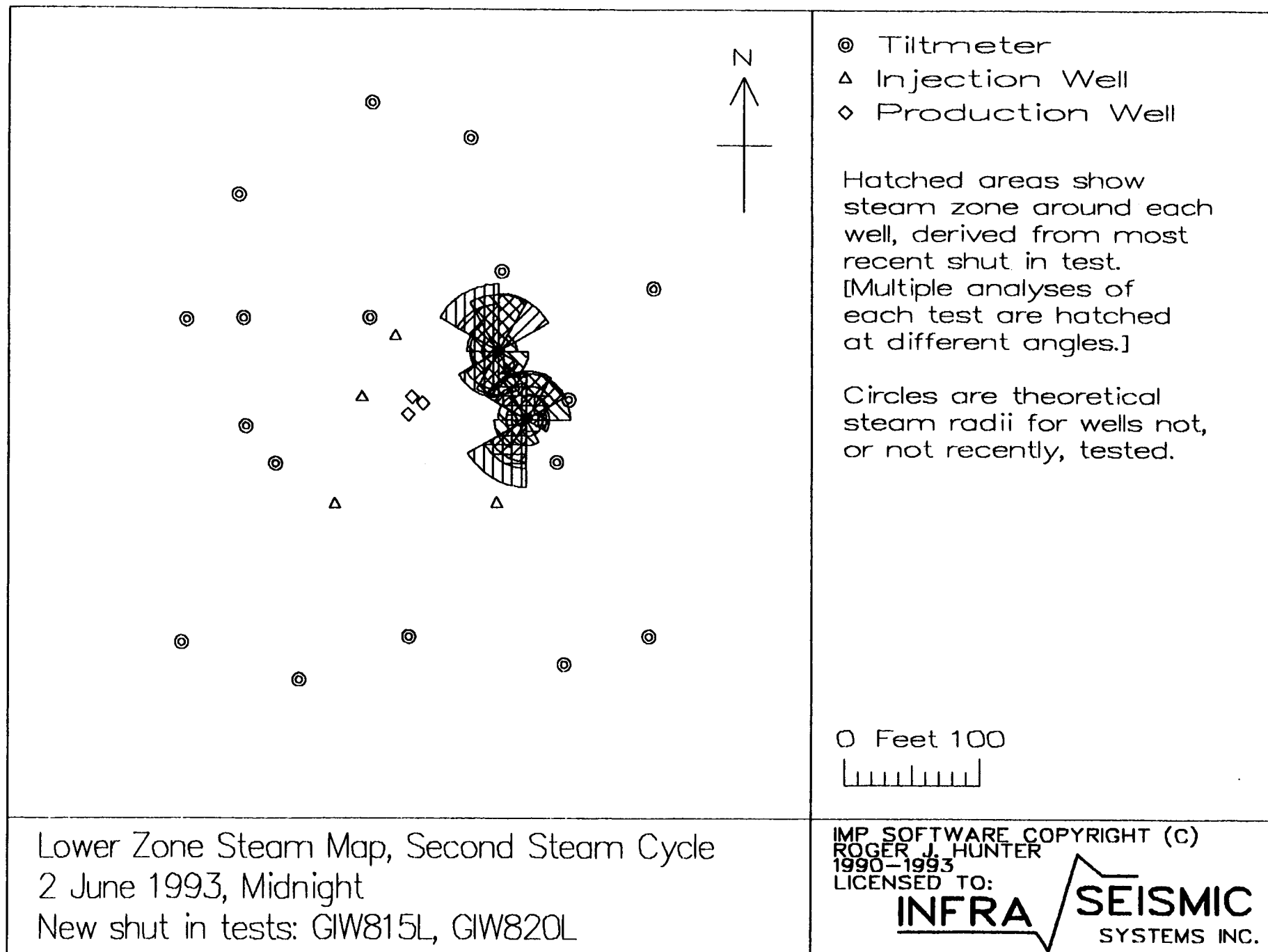
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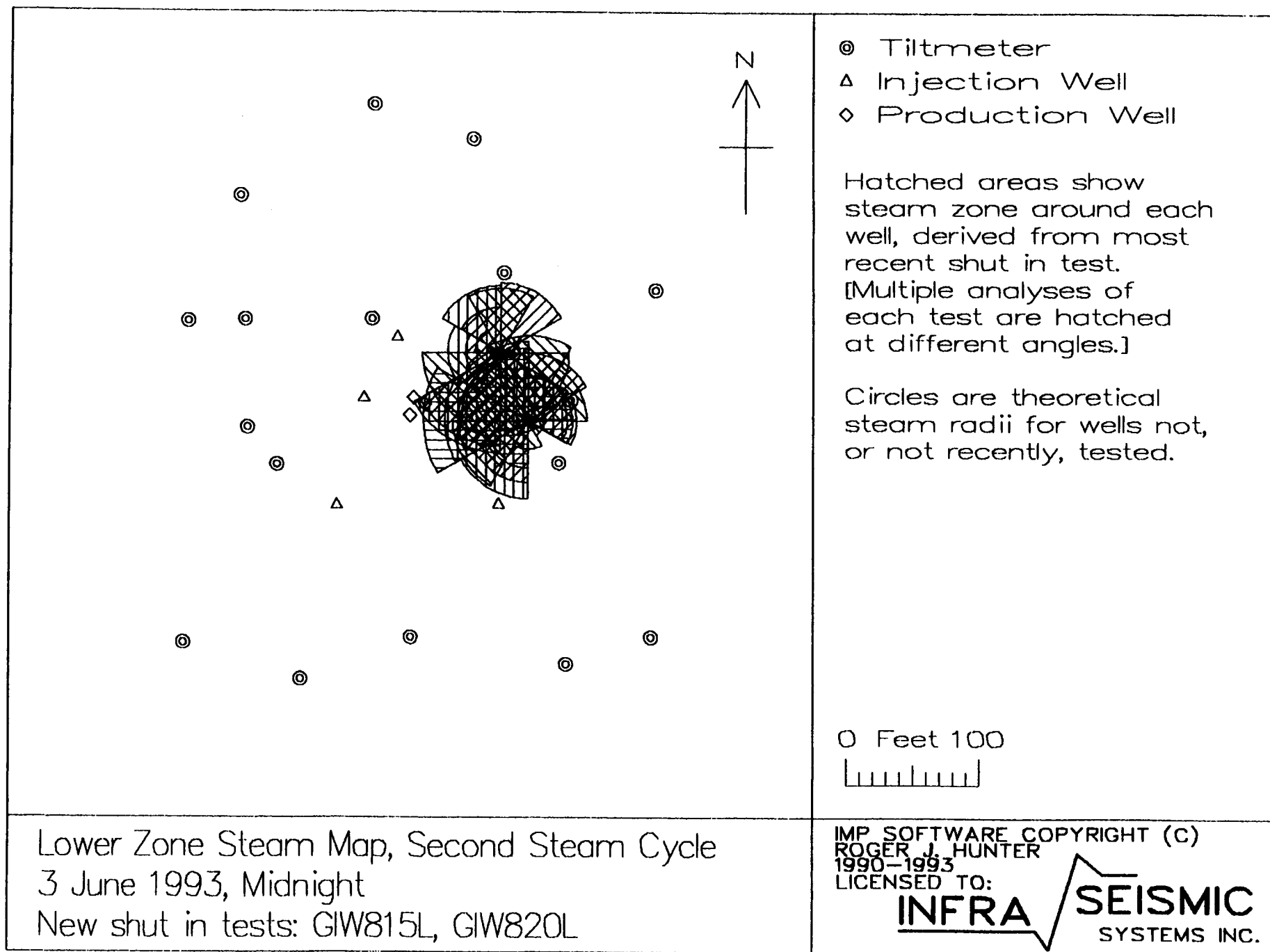


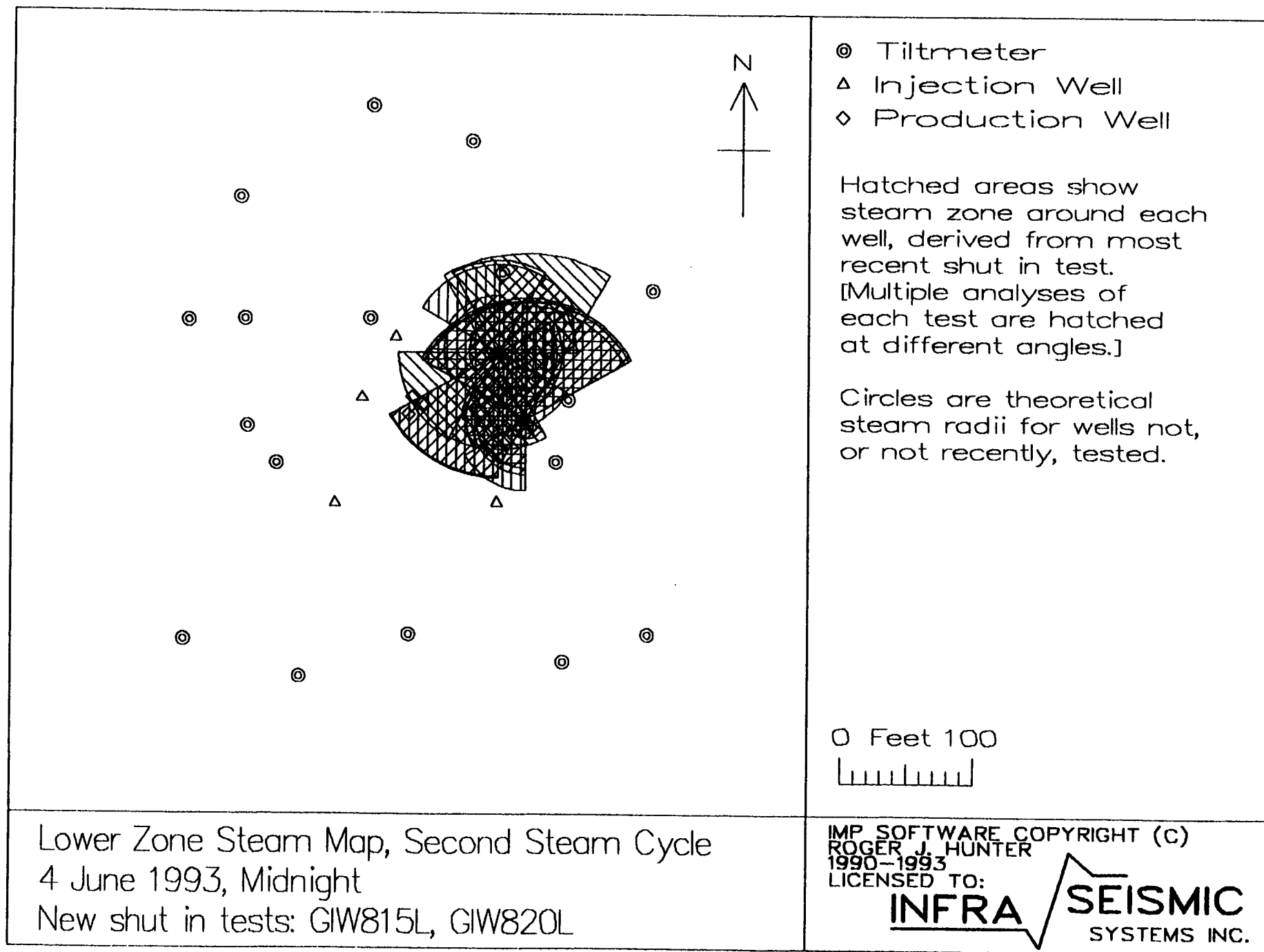
Upper Zone Steam Map, First Steam Cycle.
3 March 1993, 9.30 pm
New shut in tests: GIW814U, GIW818U

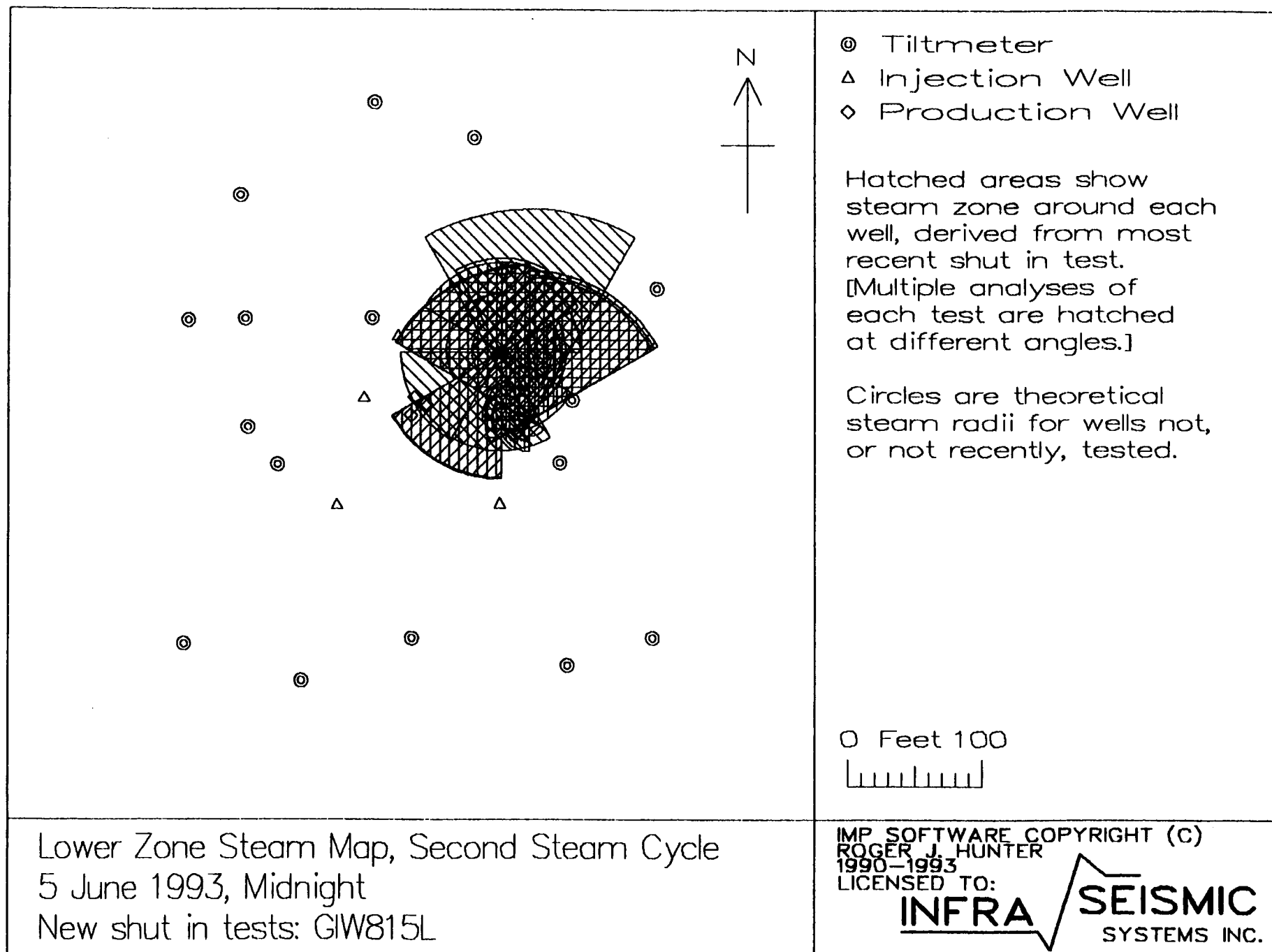
IMP SOFTWARE COPYRIGHT (C)
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LICENSED TO:

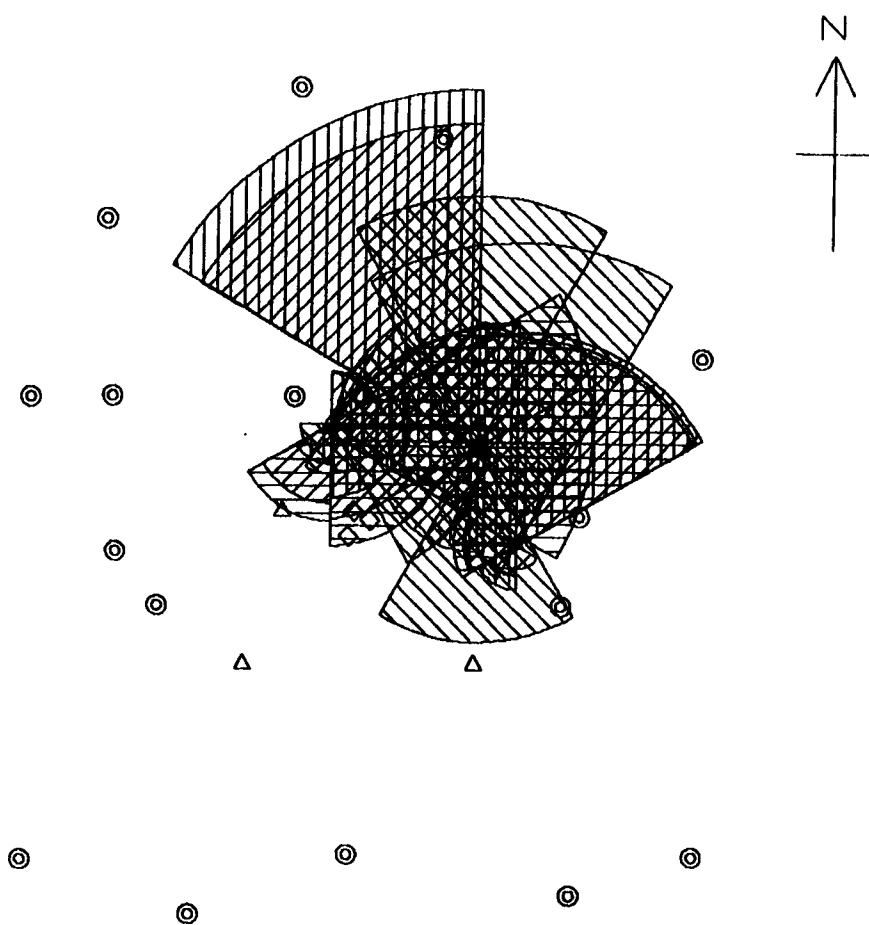
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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

0 Feet 100

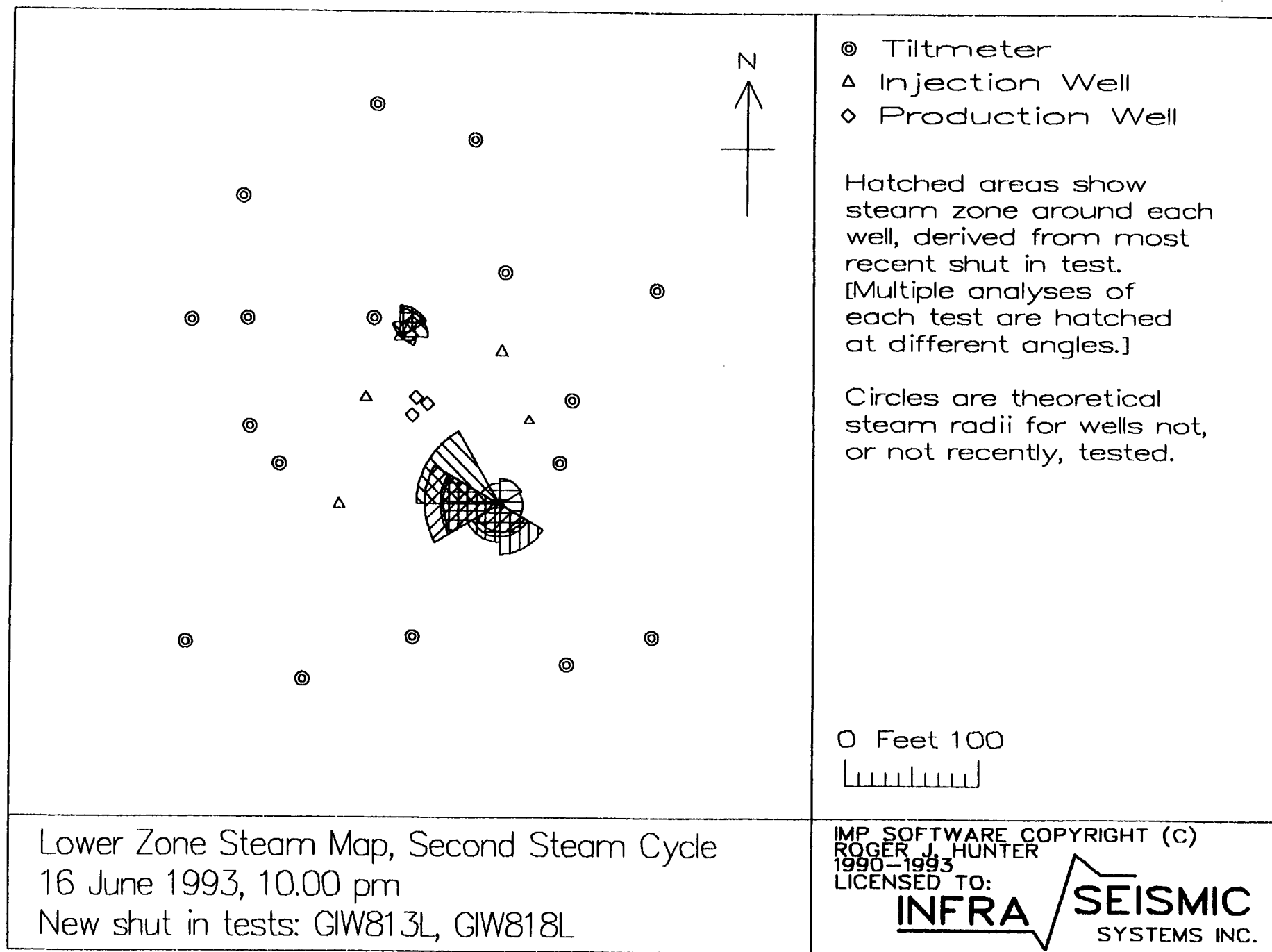


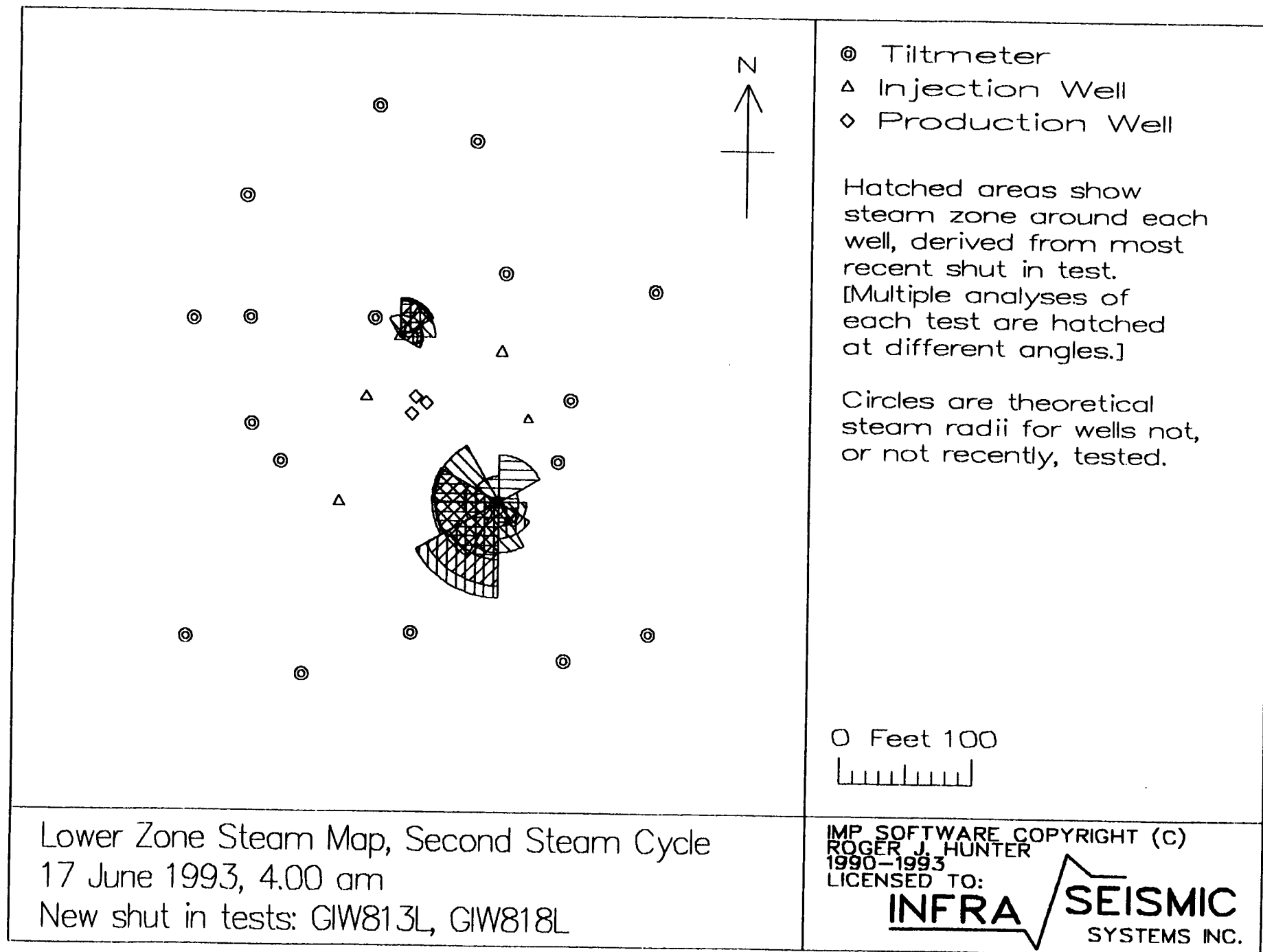
Lower Zone Steam Map, Second Steam Cycle
6 June 1993, Midnight
New shut in tests: GIW818L, GIW820L

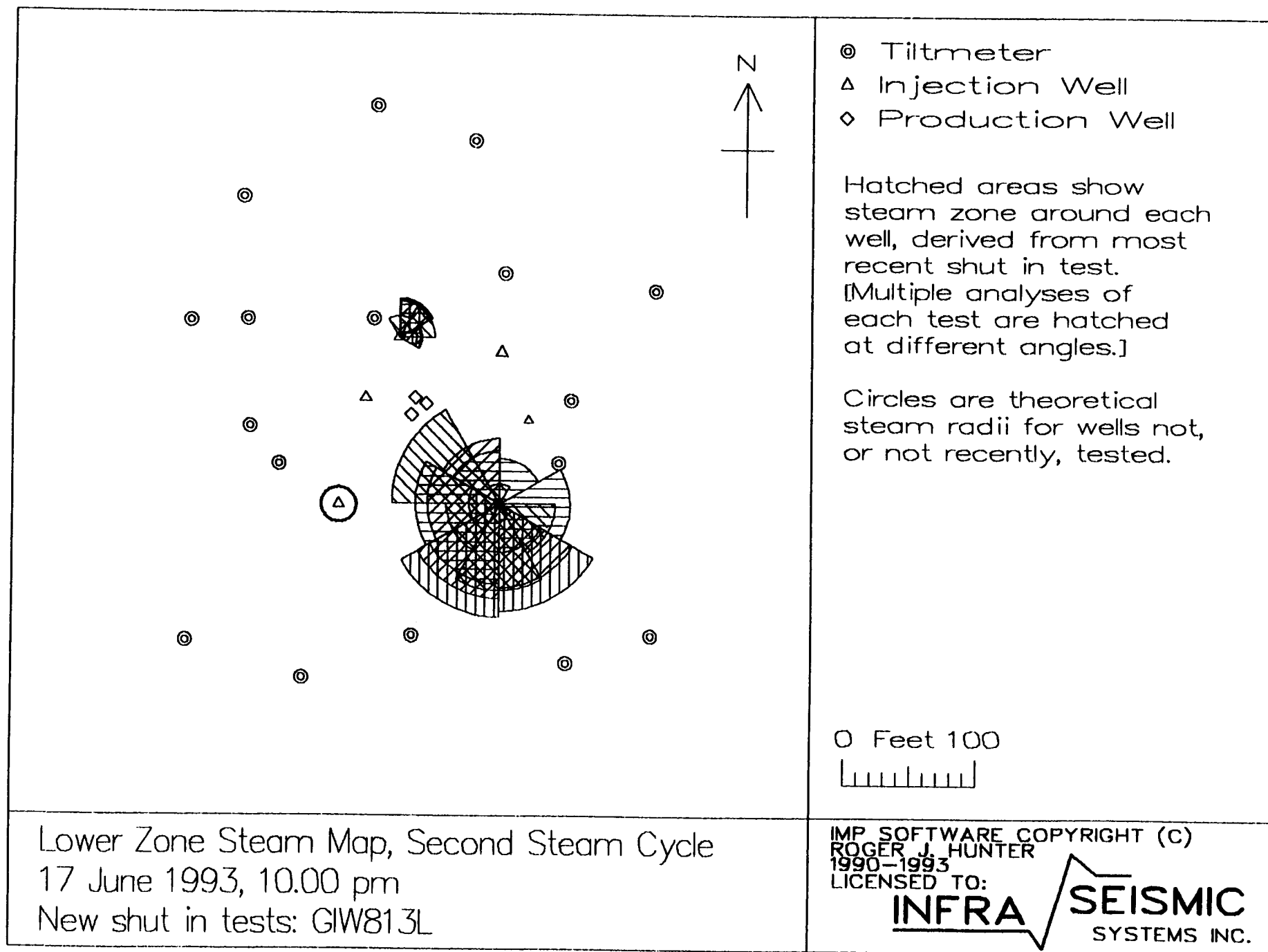
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4-240



- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

0 Feet 100

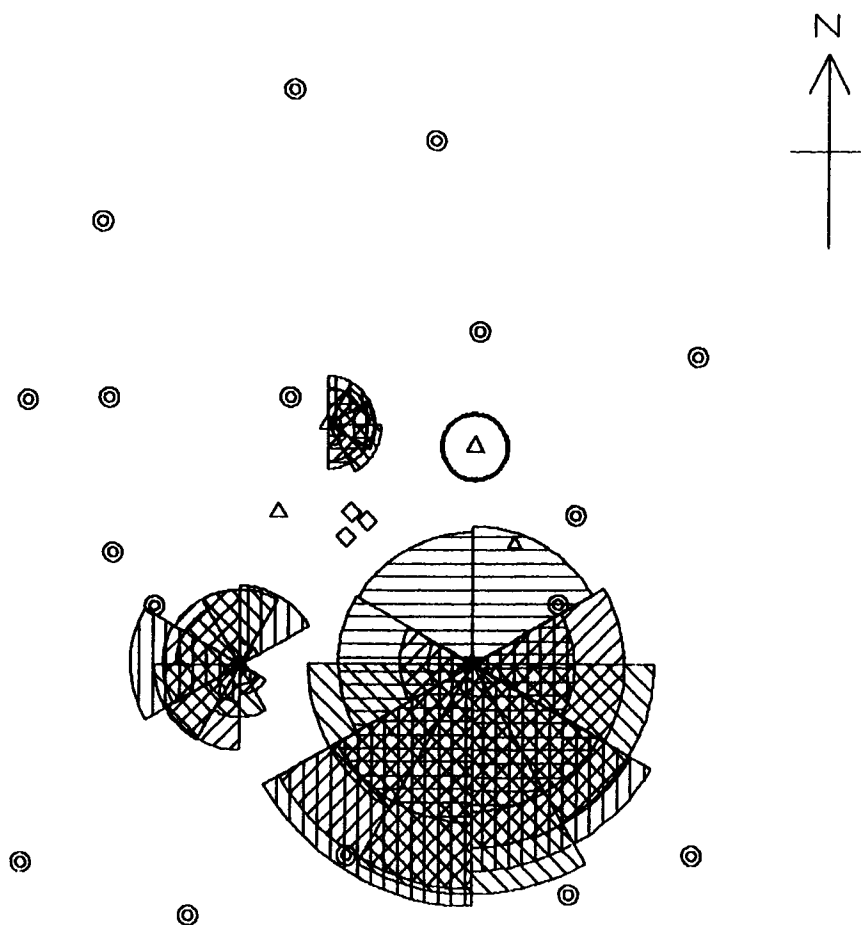


Lower Zone Steam Map, Second Steam Cycle
18 June 1993, 4.00 am
New shut in tests: GIW814L, GIW818L

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Figure 45



- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

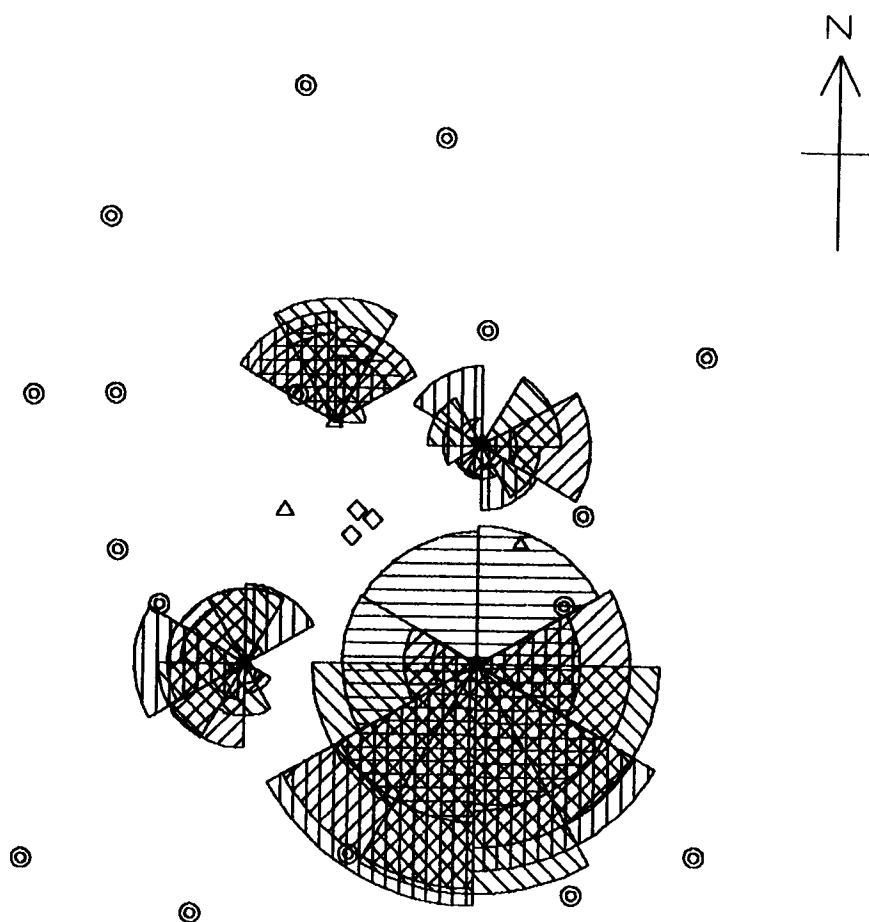
0 Feet 100



Lower Zone Steam Map, Second Steam Cycle
18 June 1993, 10.00 pm
New shut in tests: GIW813L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

0 Feet 100



Lower Zone Steam Map, Second Steam Cycle
19 June 1993, 4.00 am
New shut in tests: GIW818L, GIW820L

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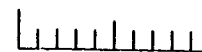
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SYSTEMS INC.

- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

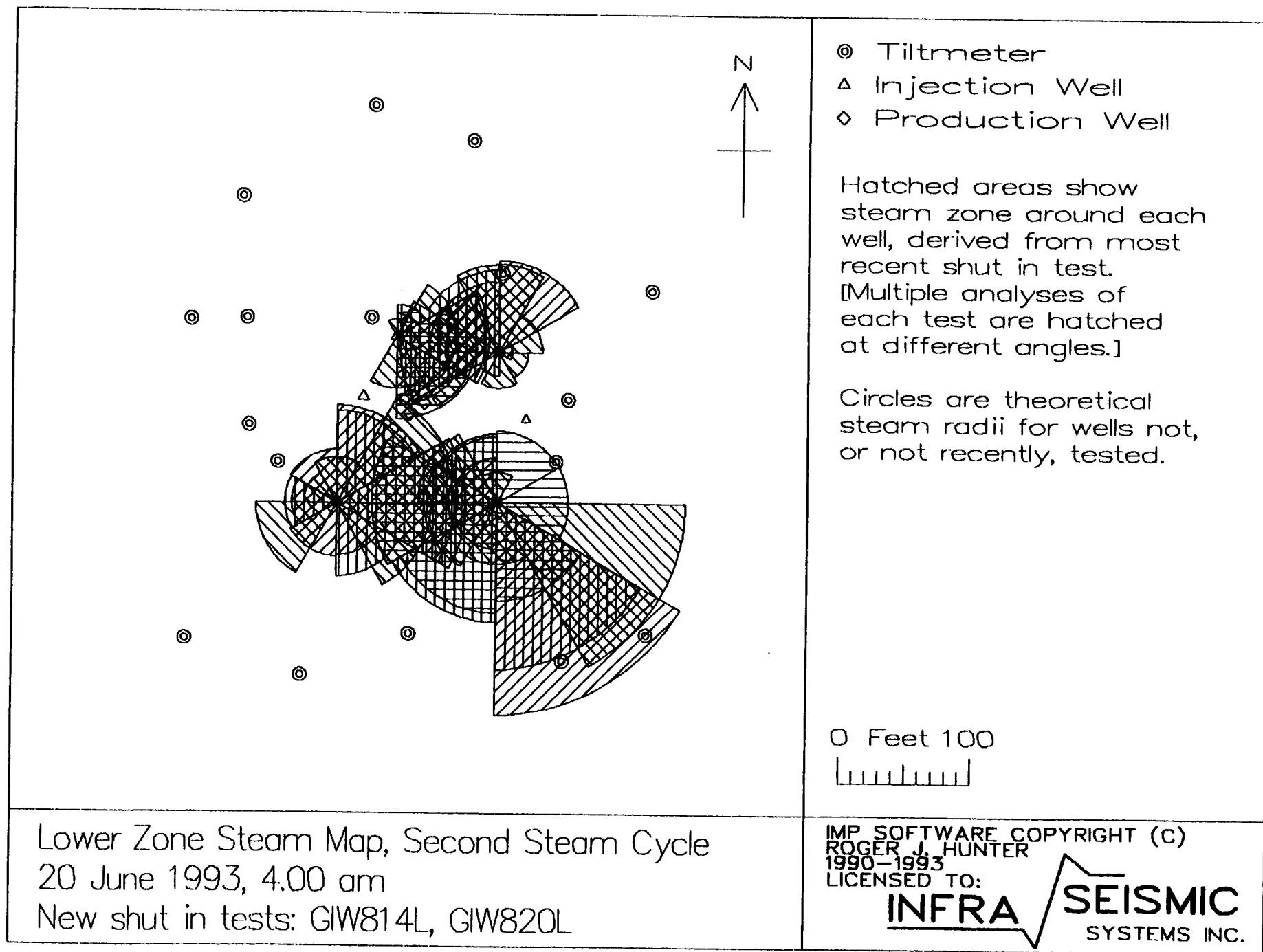
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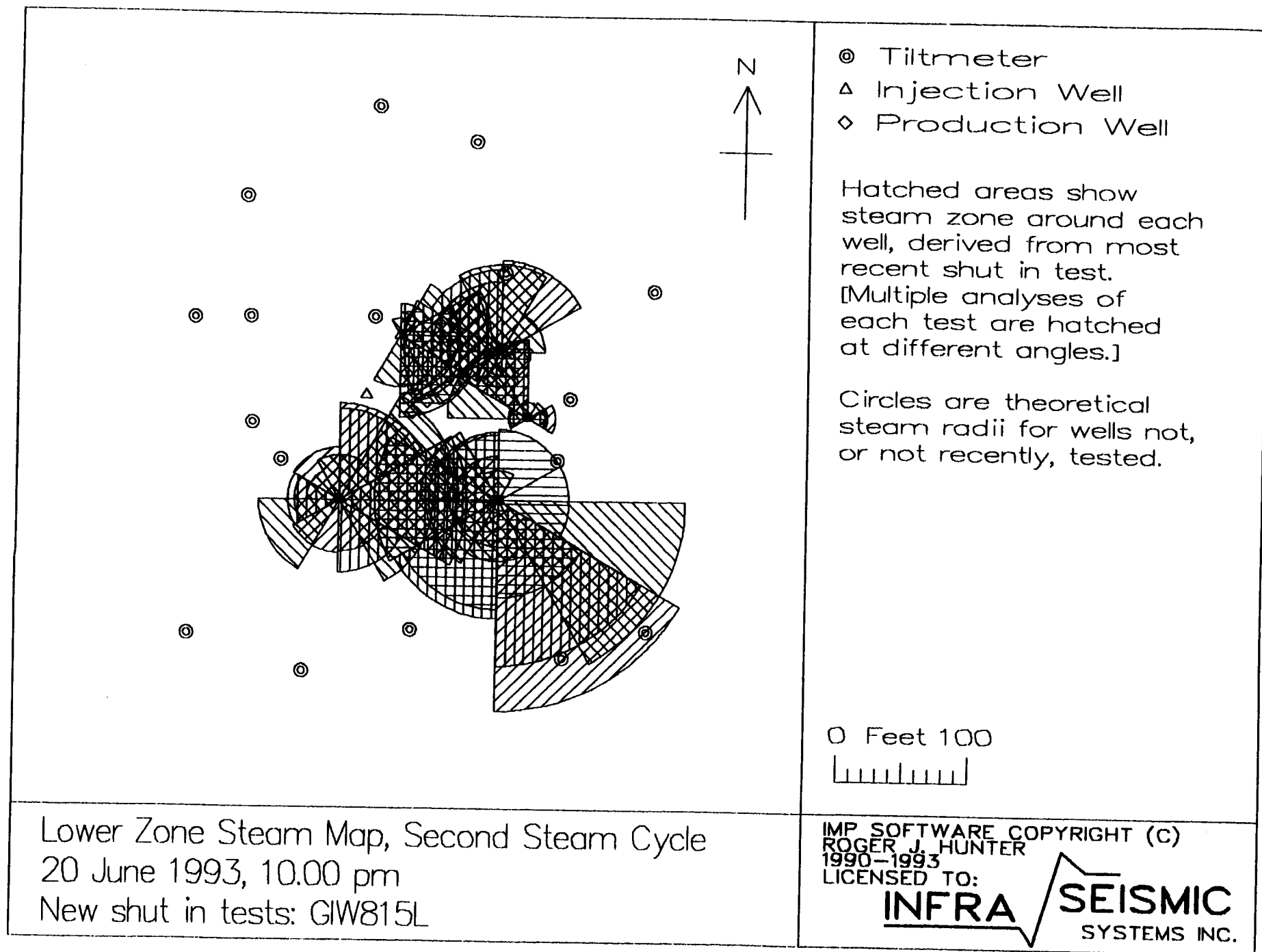


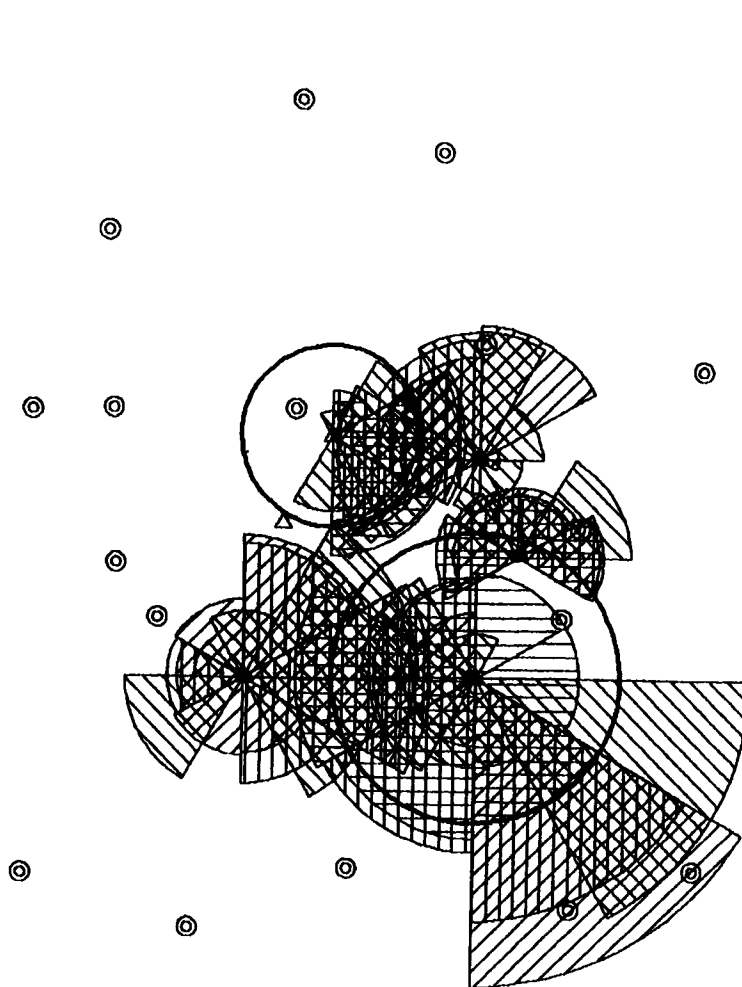
Lower Zone Steam Map, Second Steam Cycle
19 June 1993, 10.00 pm
New shut in tests: GIW813L, GIW818L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

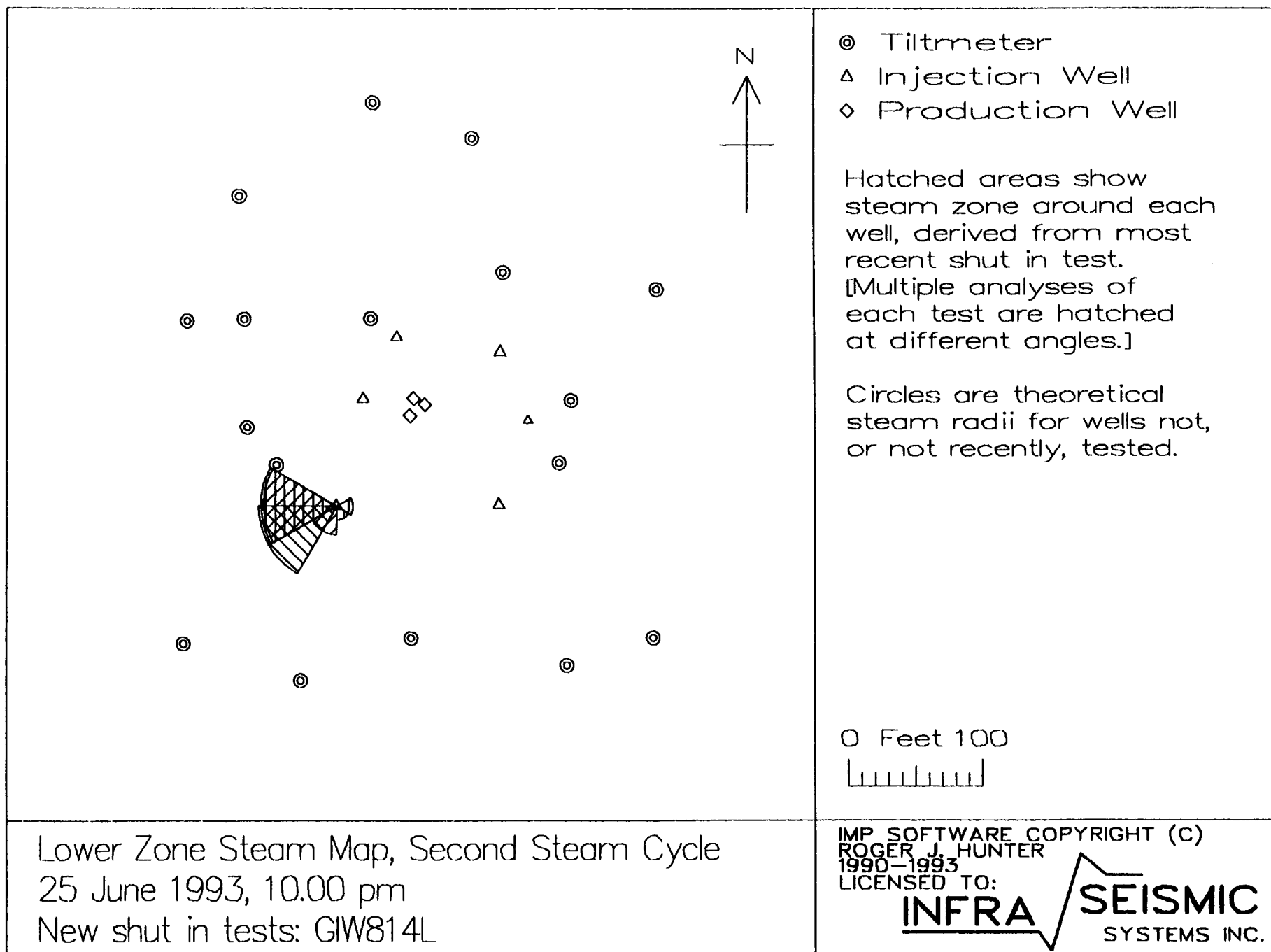
0 Feet 100

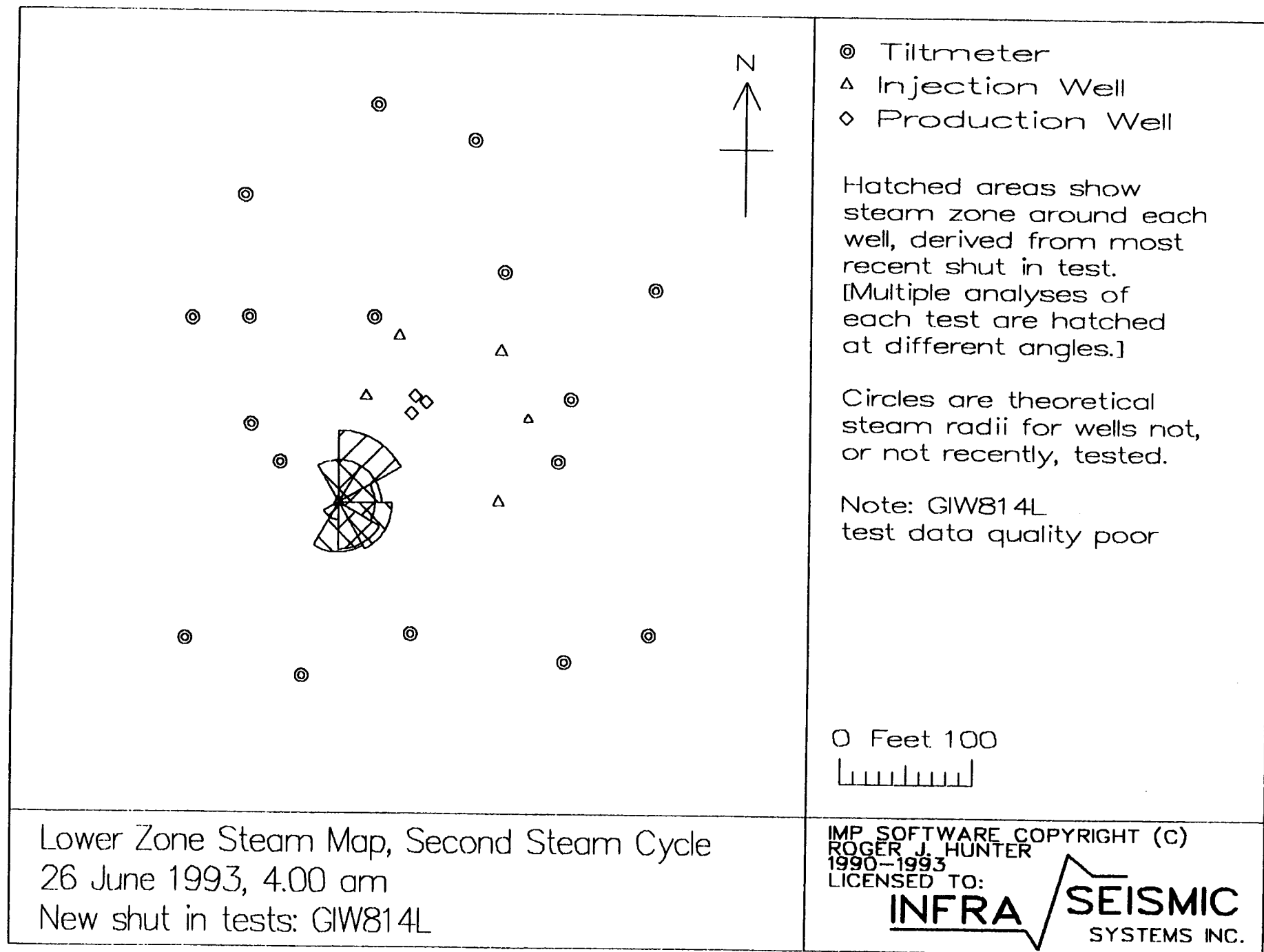


Lower Zone Steam Map, Second Steam Cycle
21 June 1993, 4.00 am
New shut in tests: GIW815L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

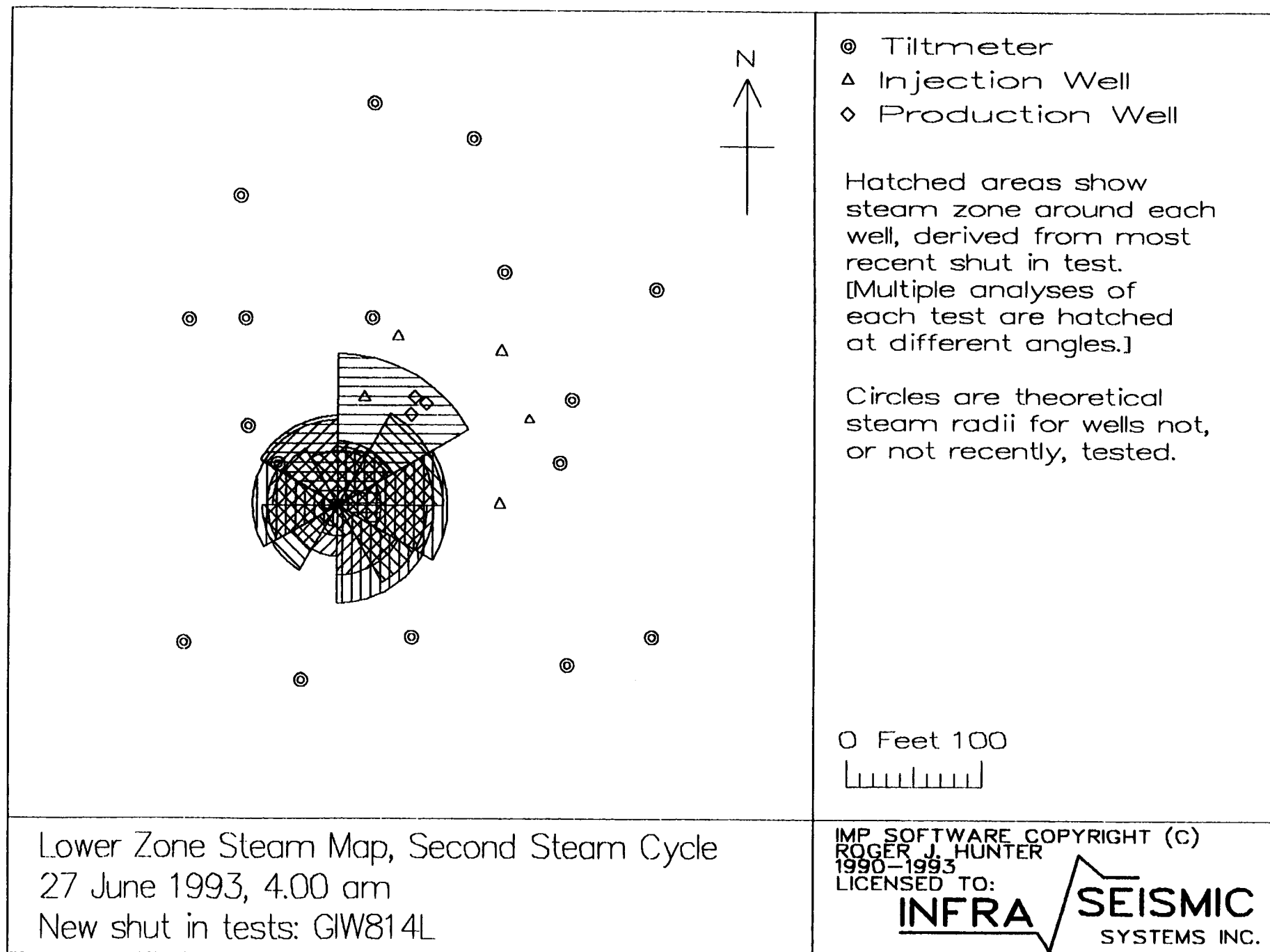
0 Feet 100

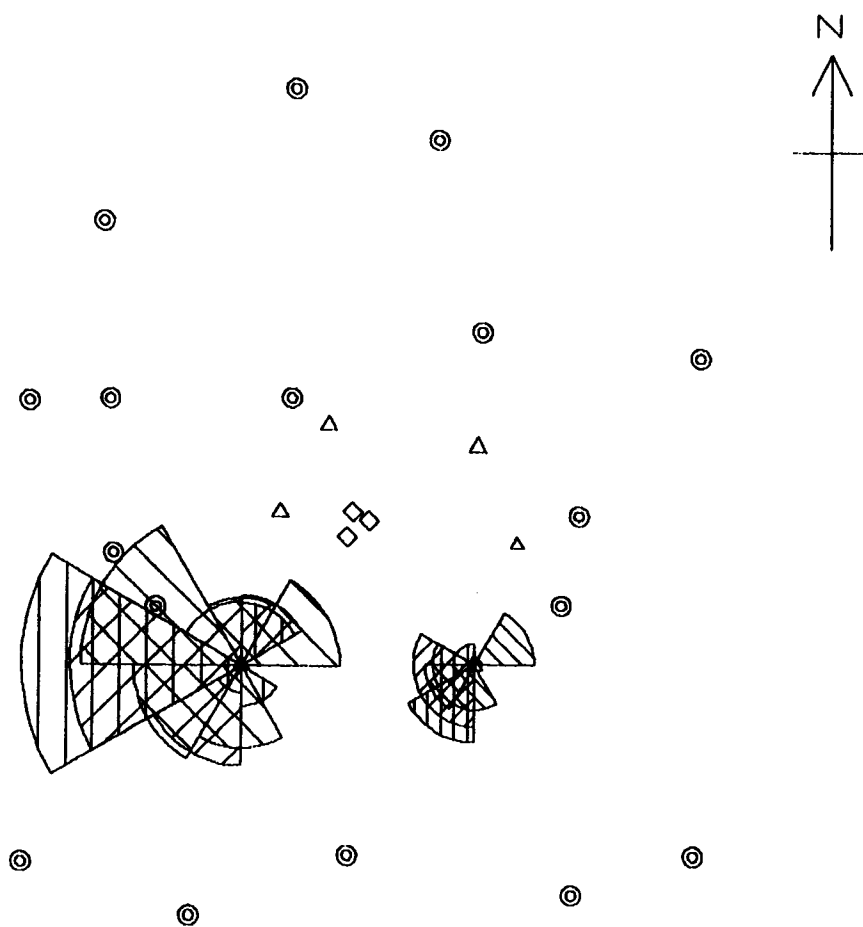


Lower Zone Steam Map, Second Steam Cycle
26 June 1993, 10.00 pm
New shut in tests: GIW814L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW814L
test data quality poor

0 Feet 100

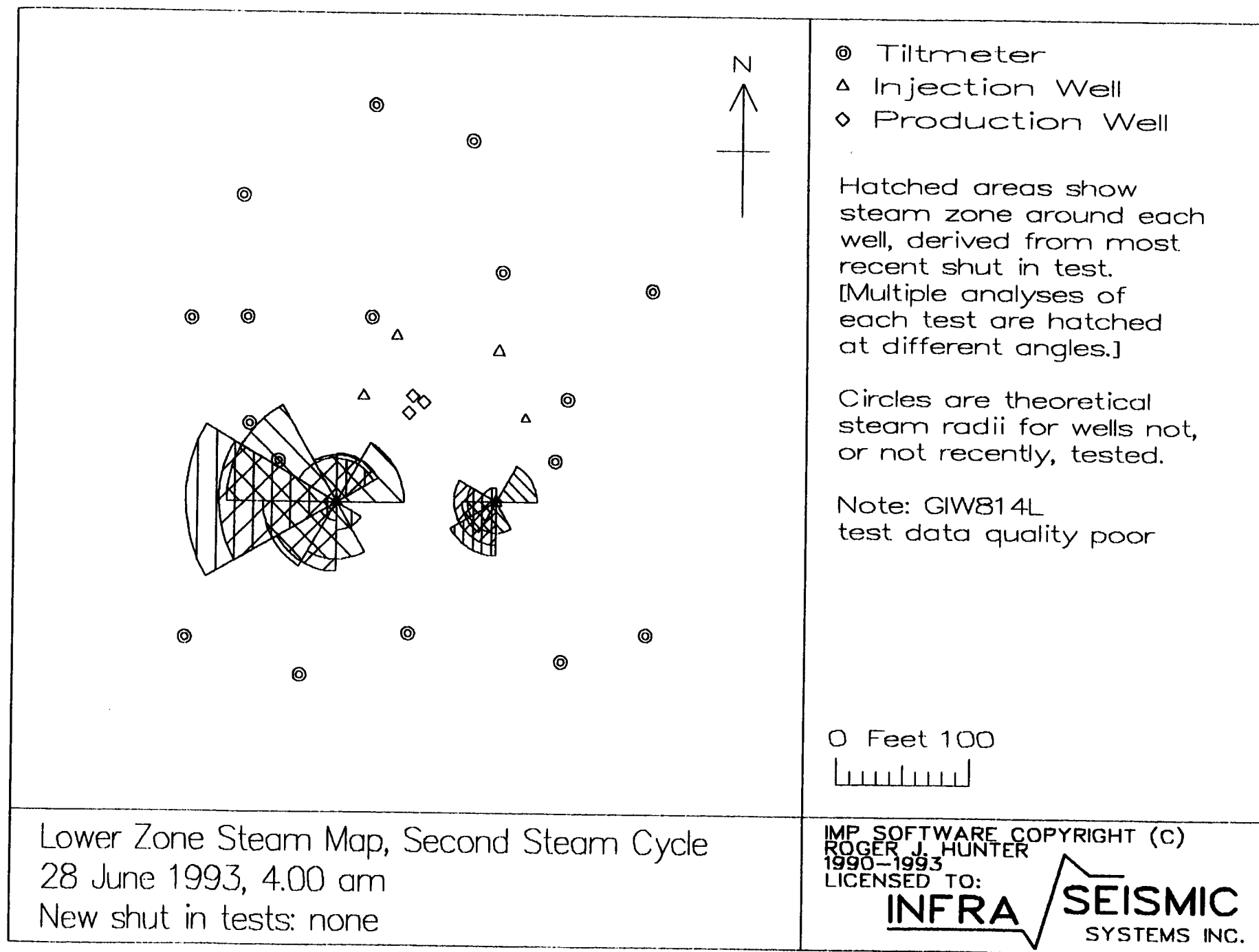


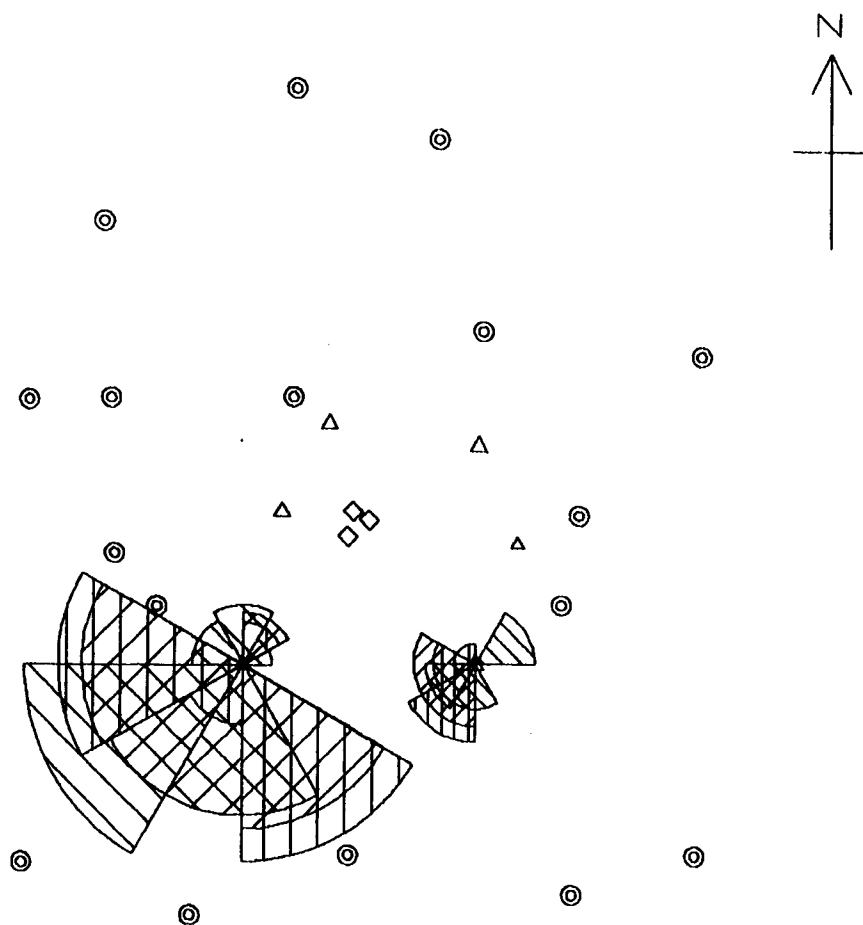
Lower Zone Steam Map, Second Steam Cycle
27 June 1993, 10.00 pm
New shut in tests: GIW813L, GIW814L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW814L
test data quality poor

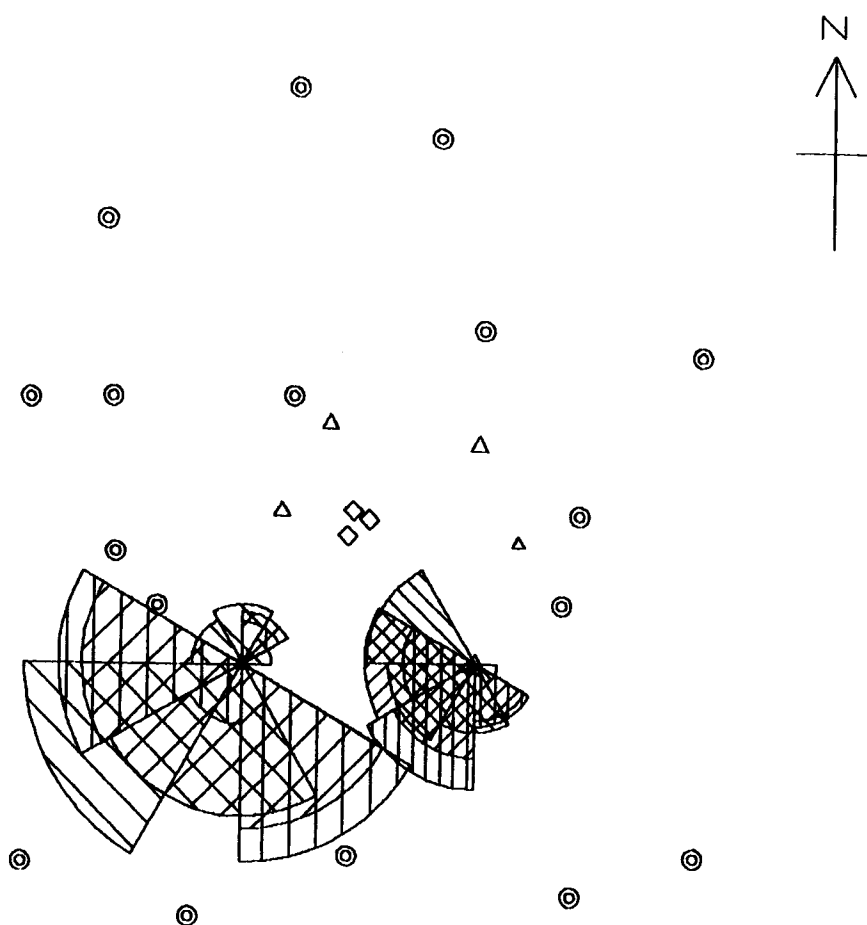
0 Feet 100



Lower Zone Steam Map, Second Steam Cycle
28 June 1993, 10.00 pm
New shut in tests: GIW814L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW814L
test data quality poor

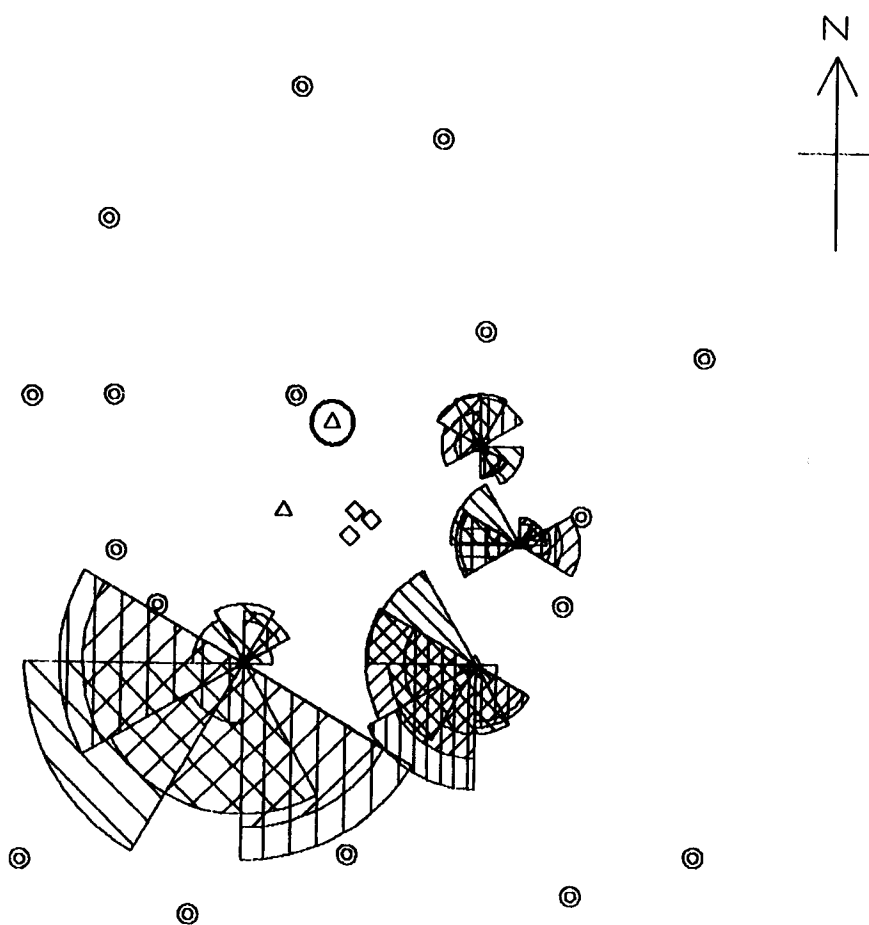
0 Feet 100



Lower Zone Steam Map, Second Steam Cycle
29 June 1993, 4.00 am
New shut in tests: GIW813L

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- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

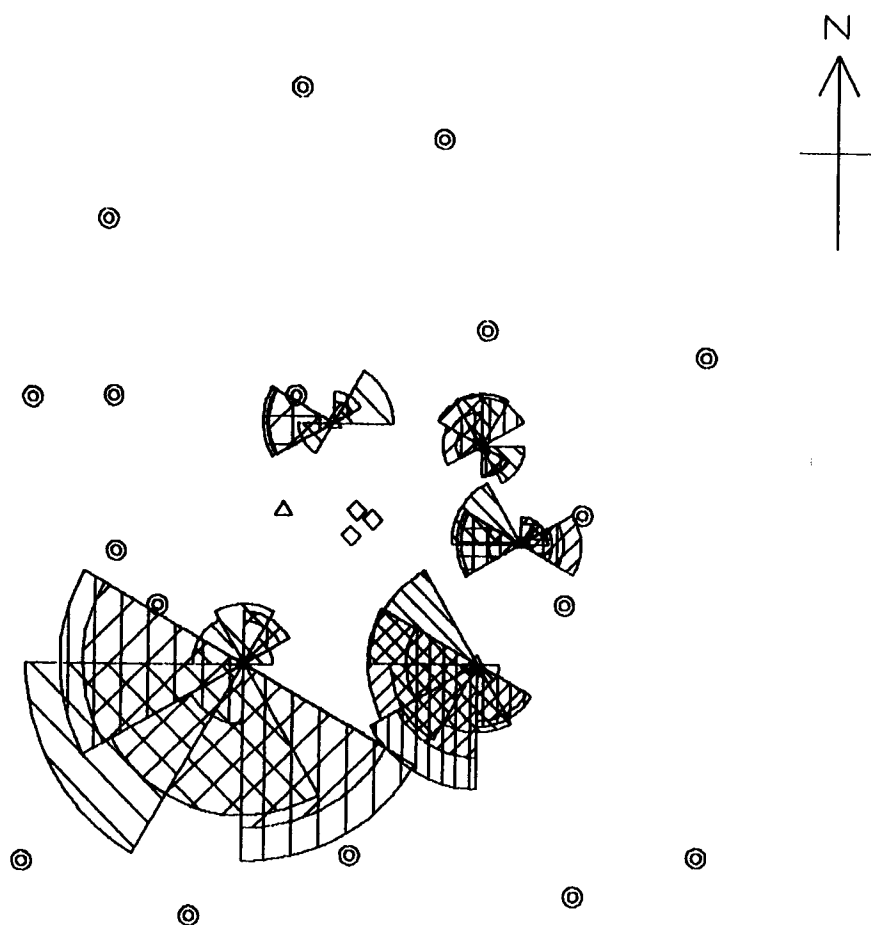
Note: GIW814L
test data quality poor

0 Feet 100
| | | | |

Lower Zone Steam Map, Second Steam Cycle
29 June 1993, 10.00 pm
New shut in tests: GIW815L, GIW820L

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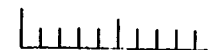
- ⊙ Tiltmeter
- △ Injection Well
- ◇ Production Well

Hatched areas show steam zone around each well, derived from most recent shut in test. [Multiple analyses of each test are hatched at different angles.]

Circles are theoretical steam radii for wells not, or not recently, tested.

Note: GIW814L, GIW818L test data quality poor

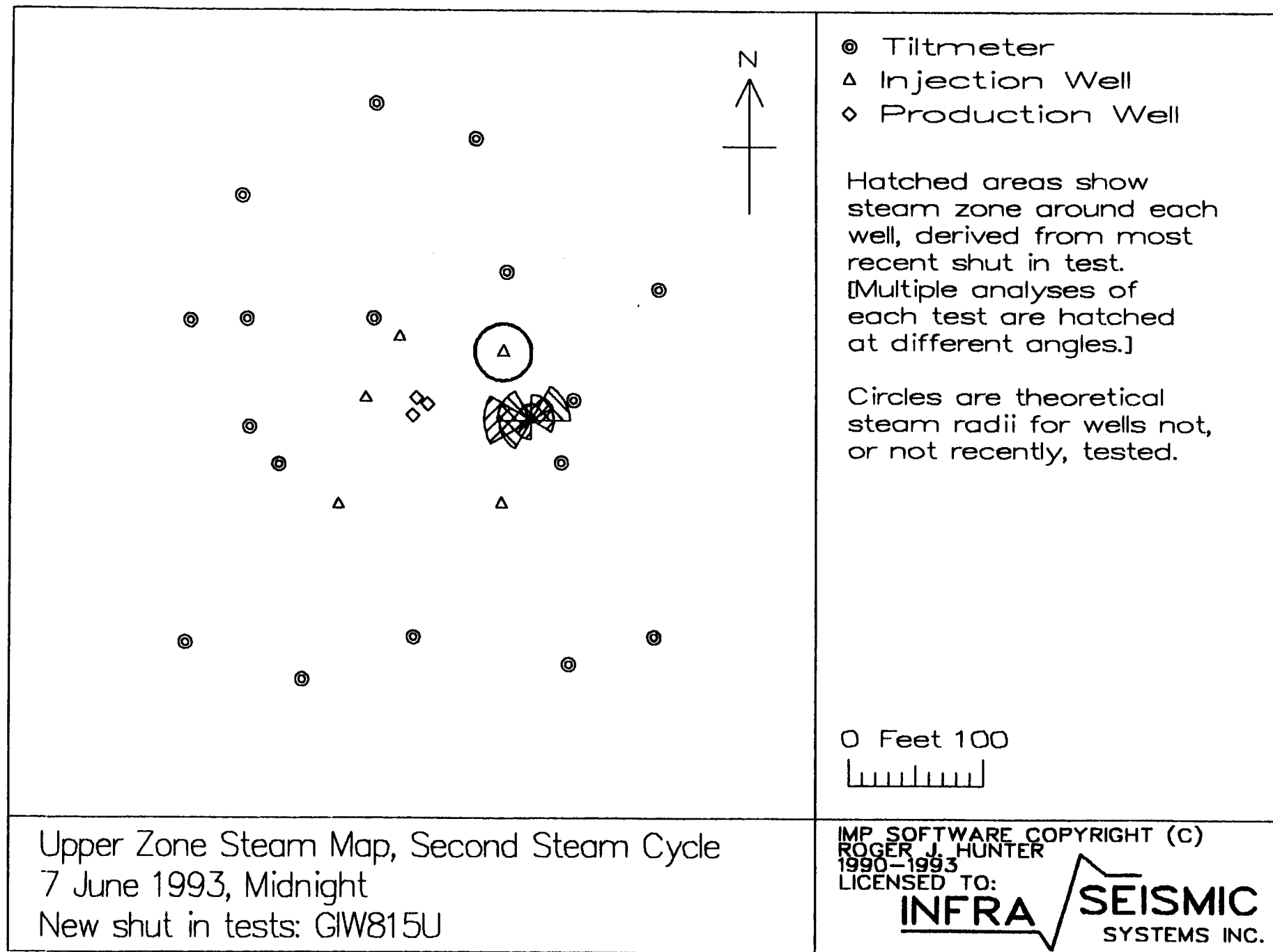
0 Feet 100

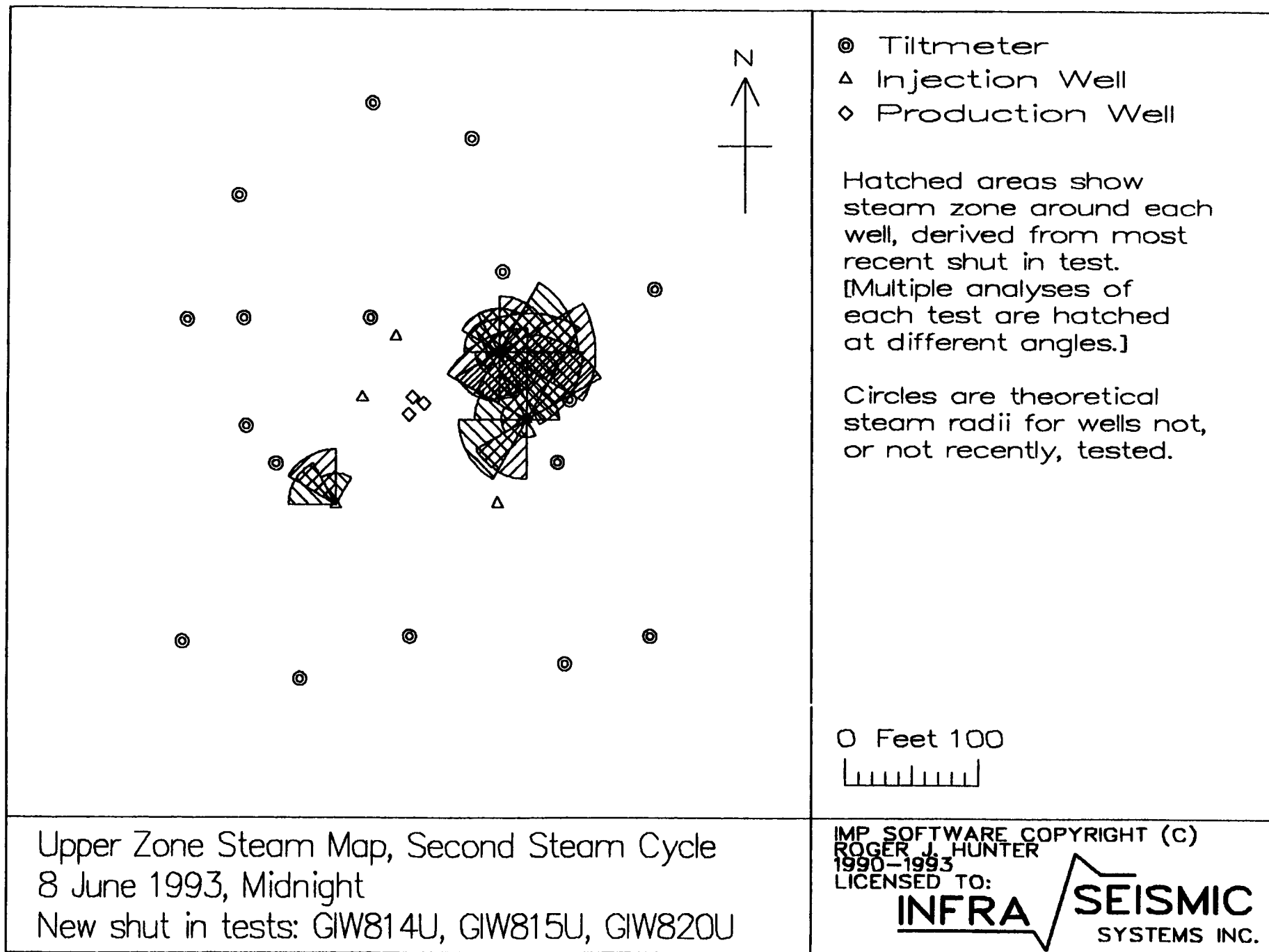


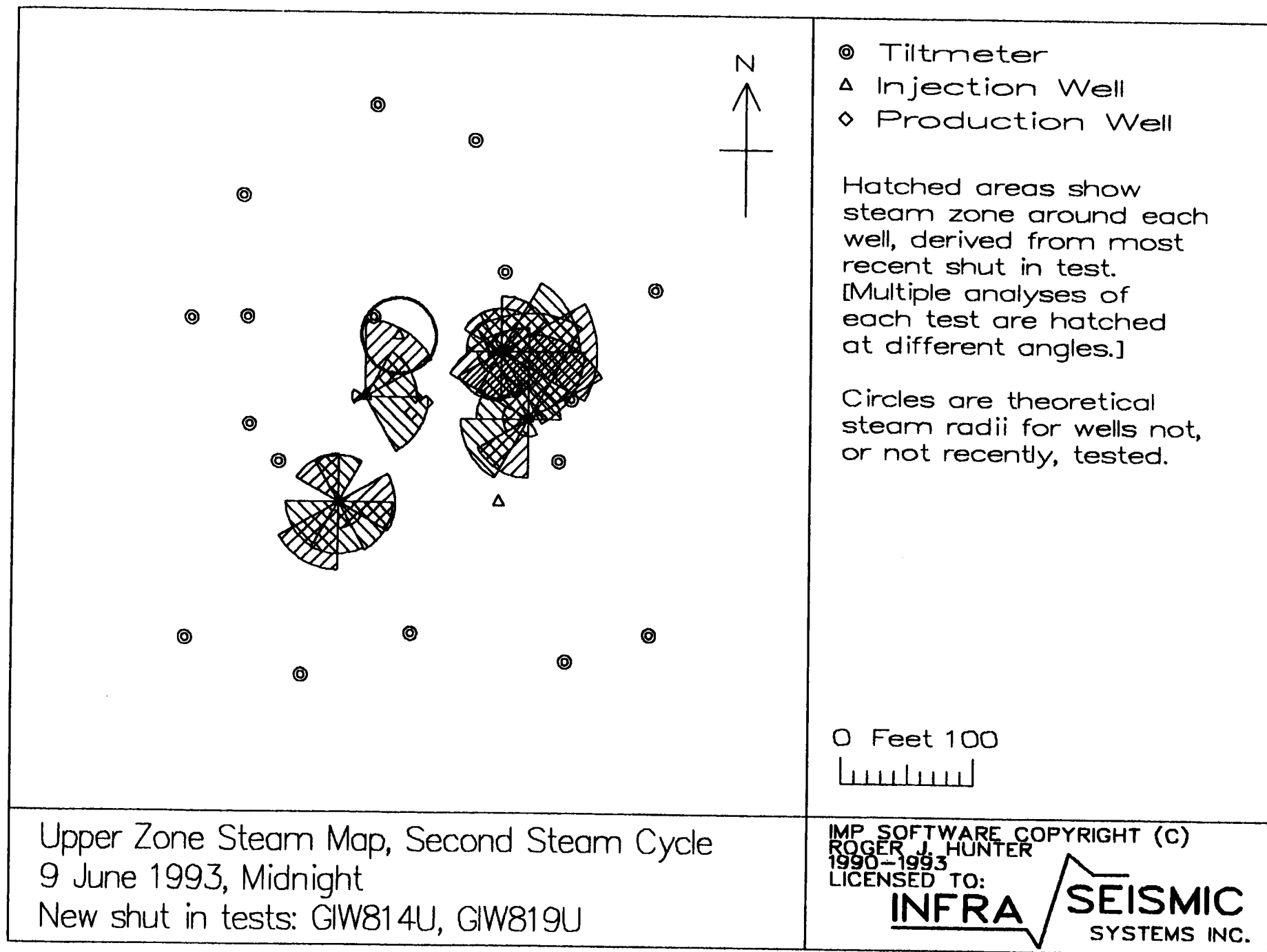
Lower Zone Steam Map, Second Steam Cycle
30 June 1993, 4.00 am
New shut in tests: GIW818L

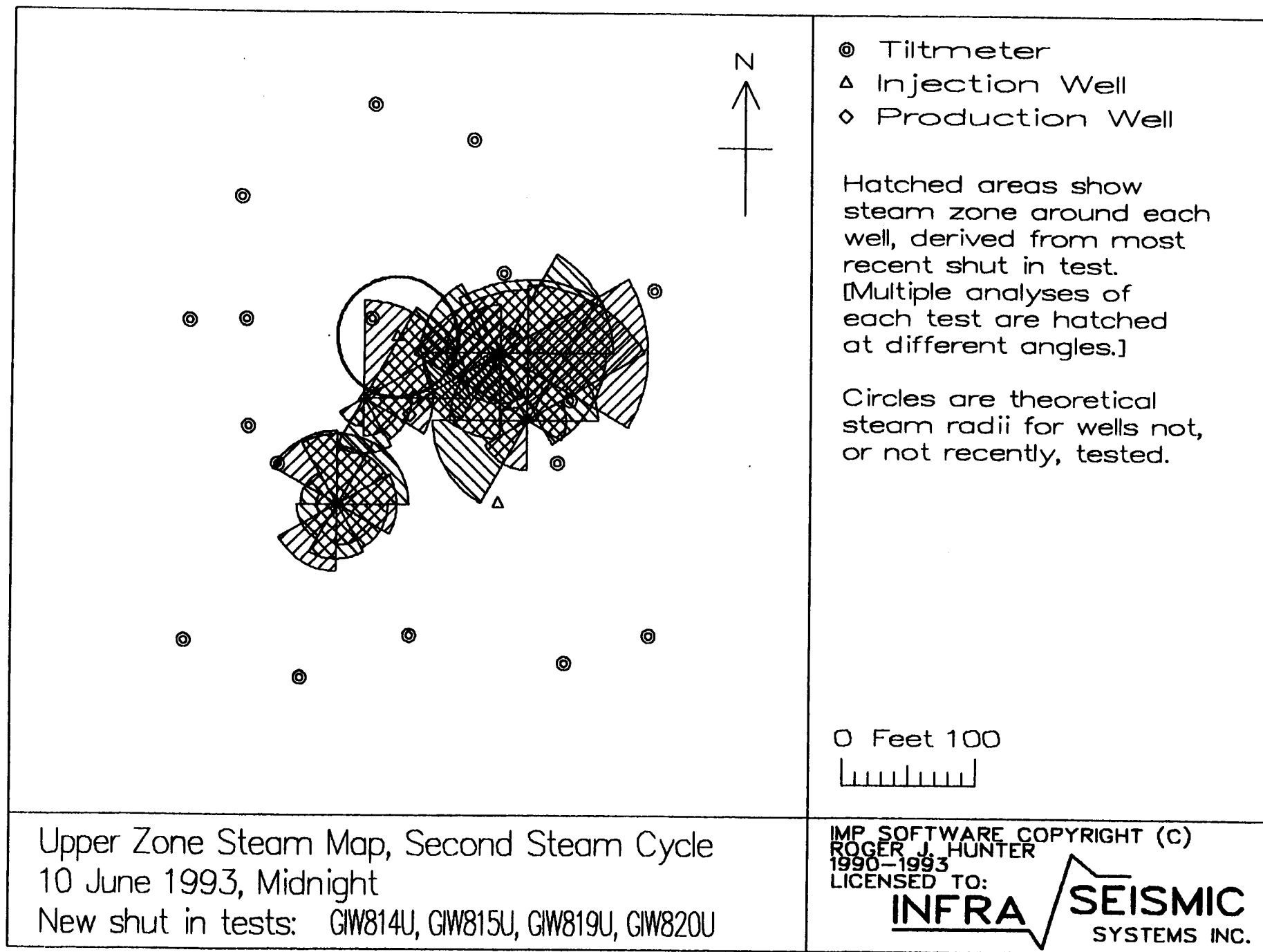
IMP SOFTWARE COPYRIGHT (C)
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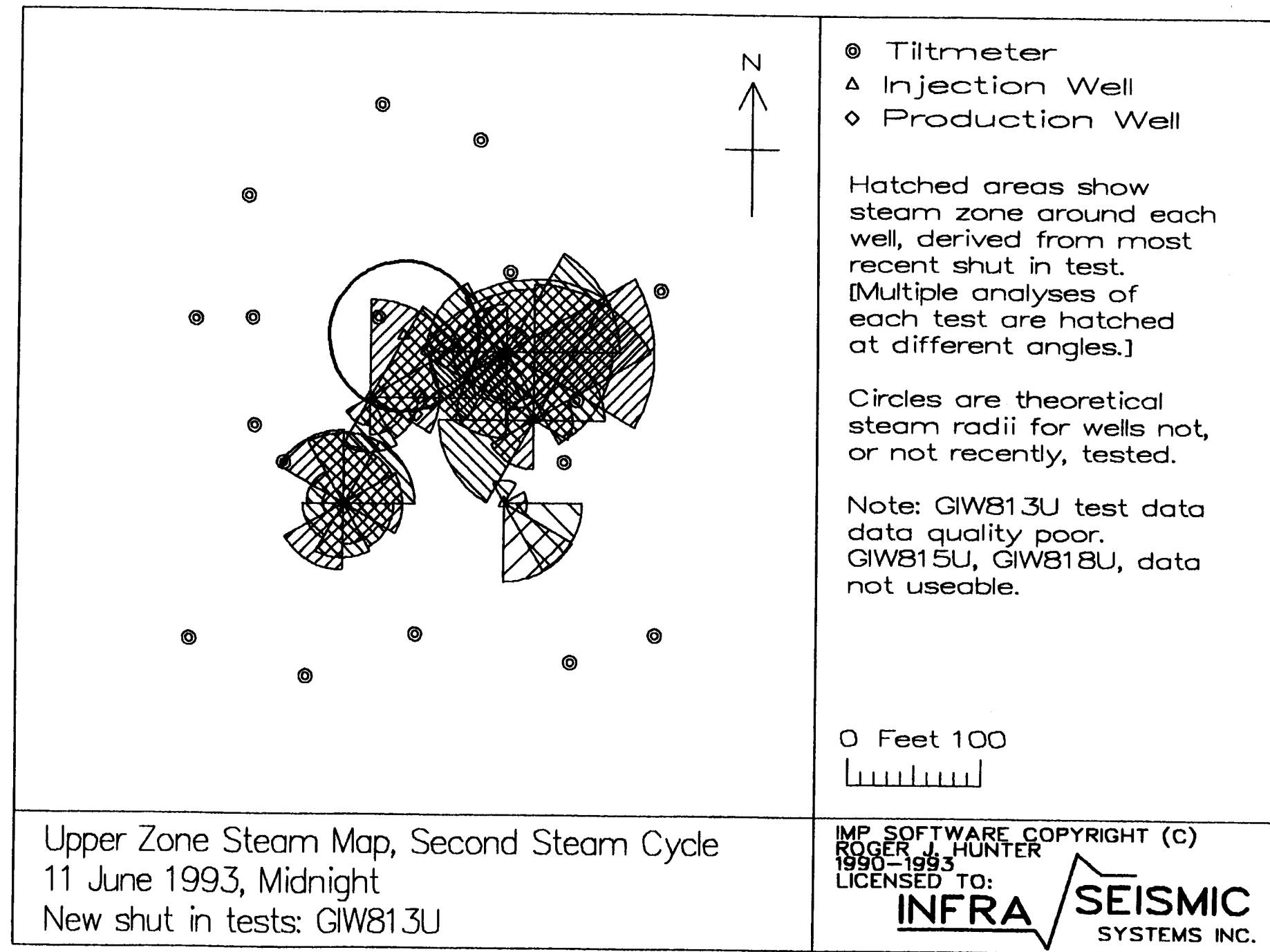
INFRA **SEISMIC**
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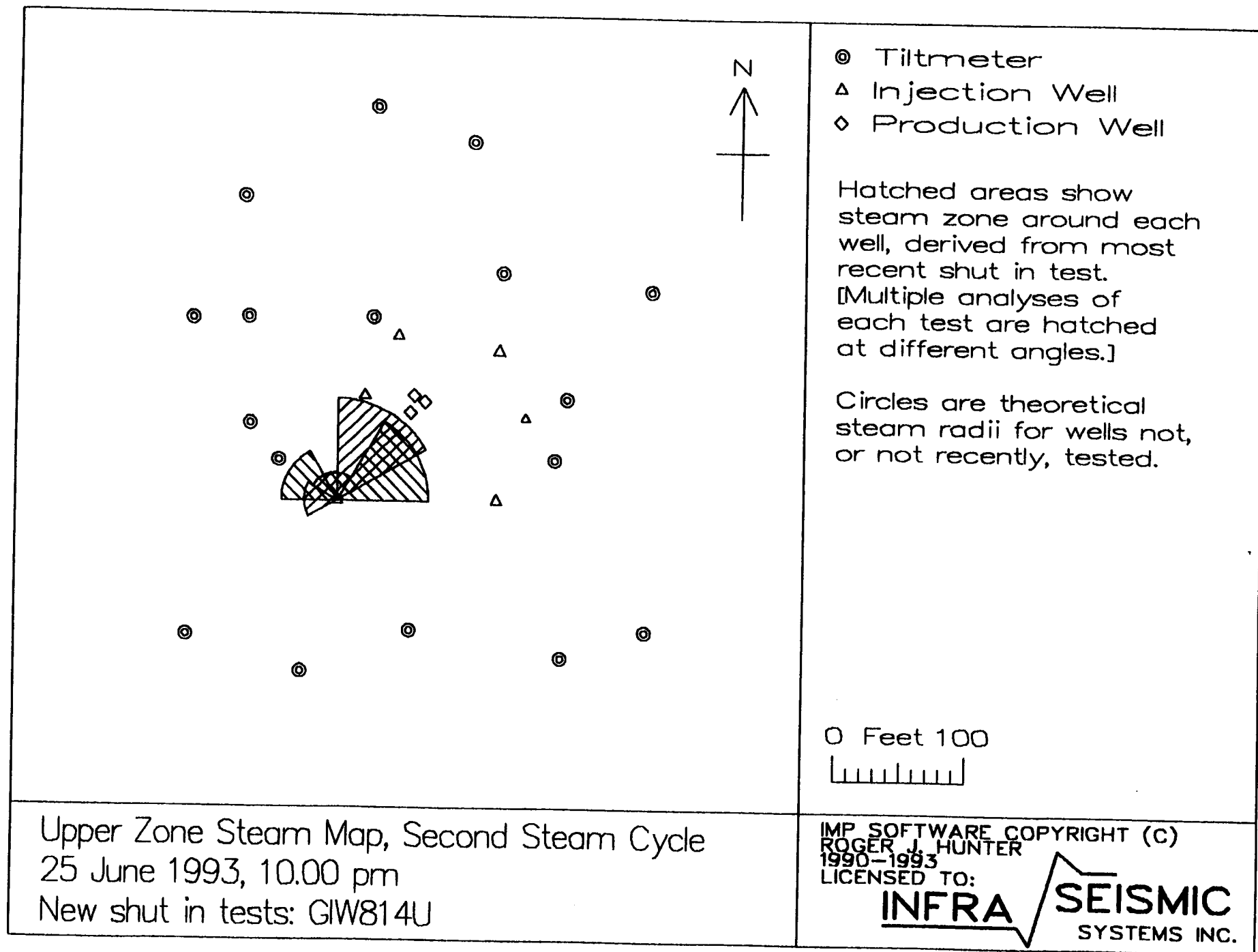


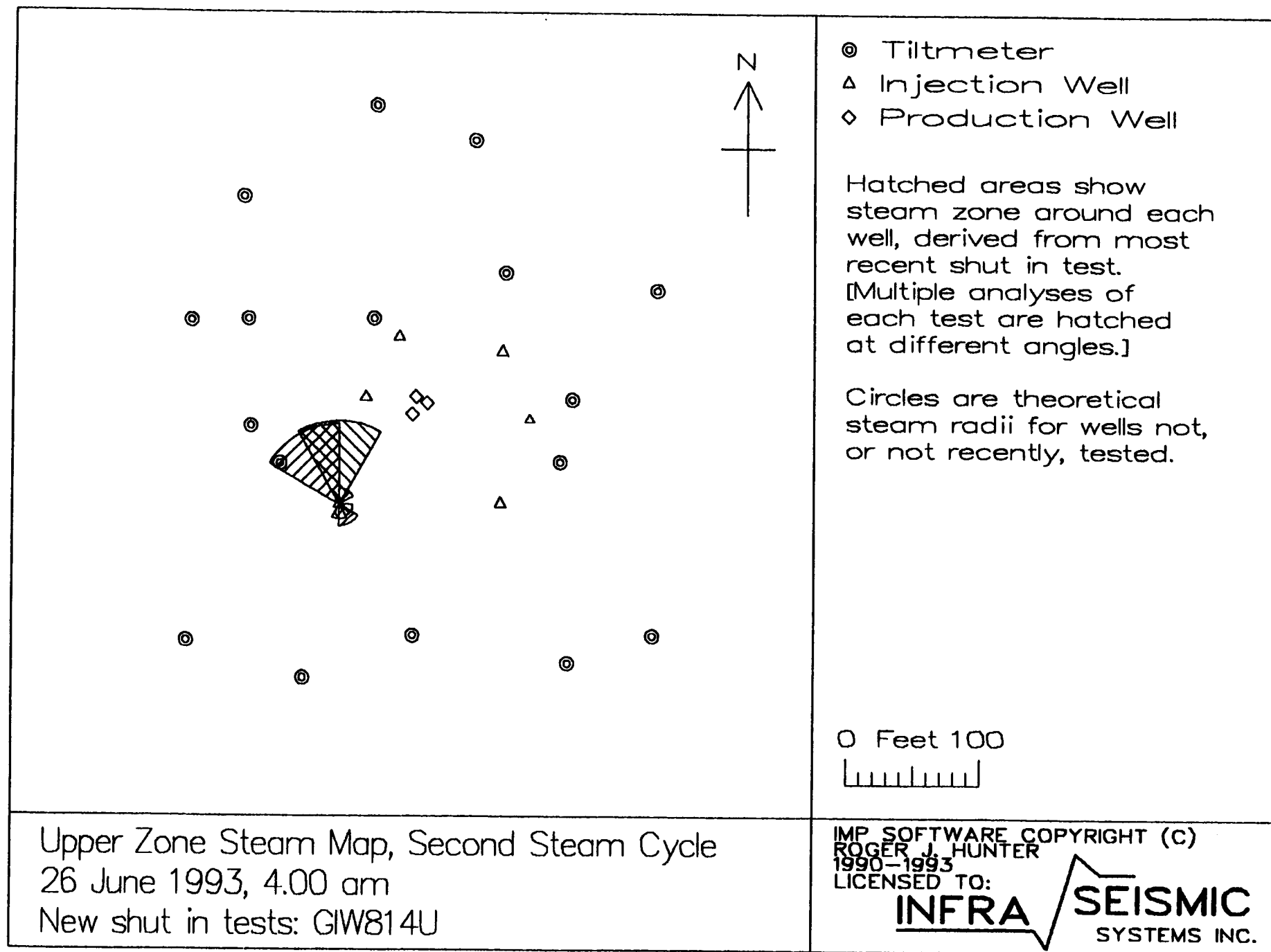


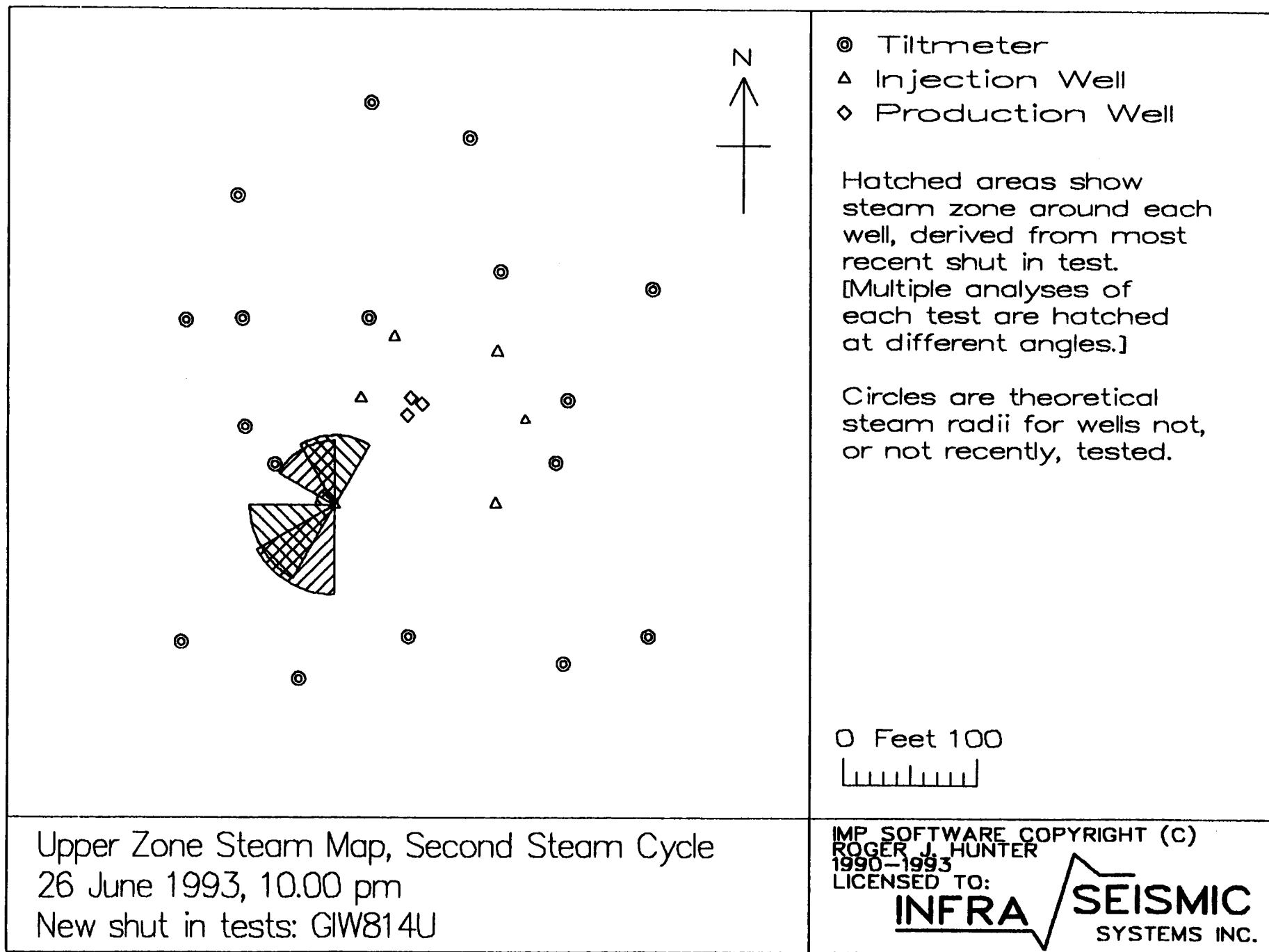


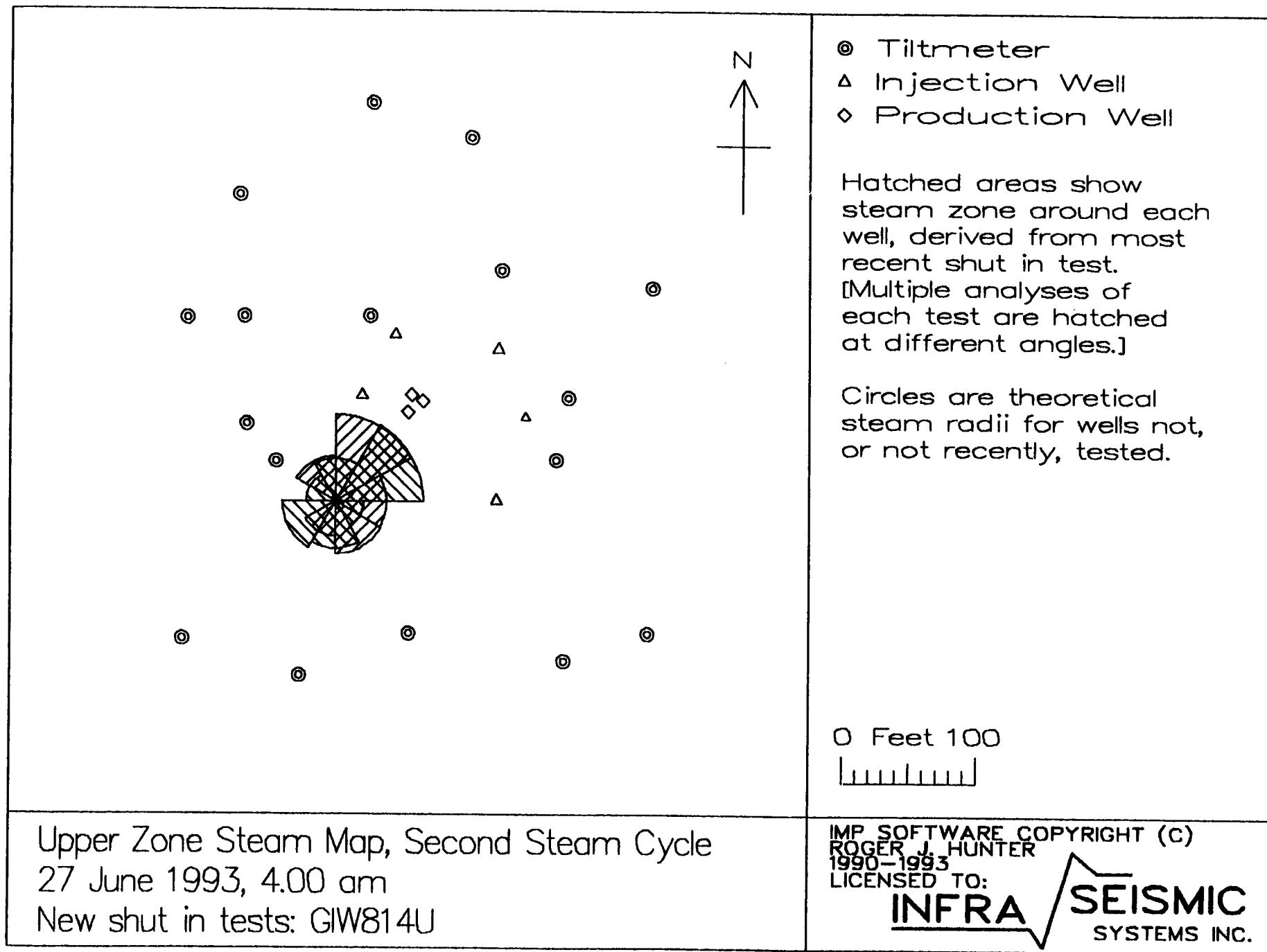


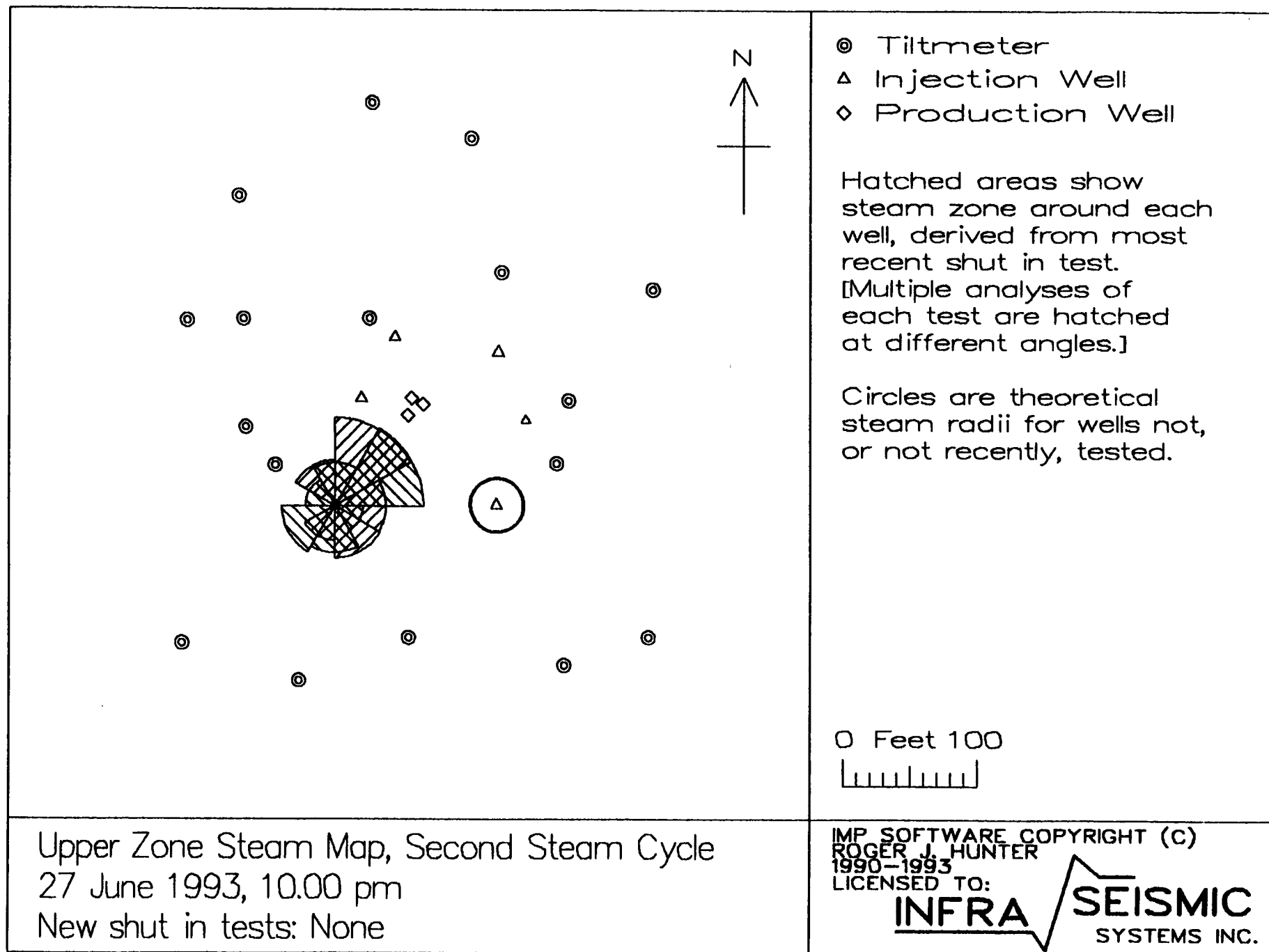


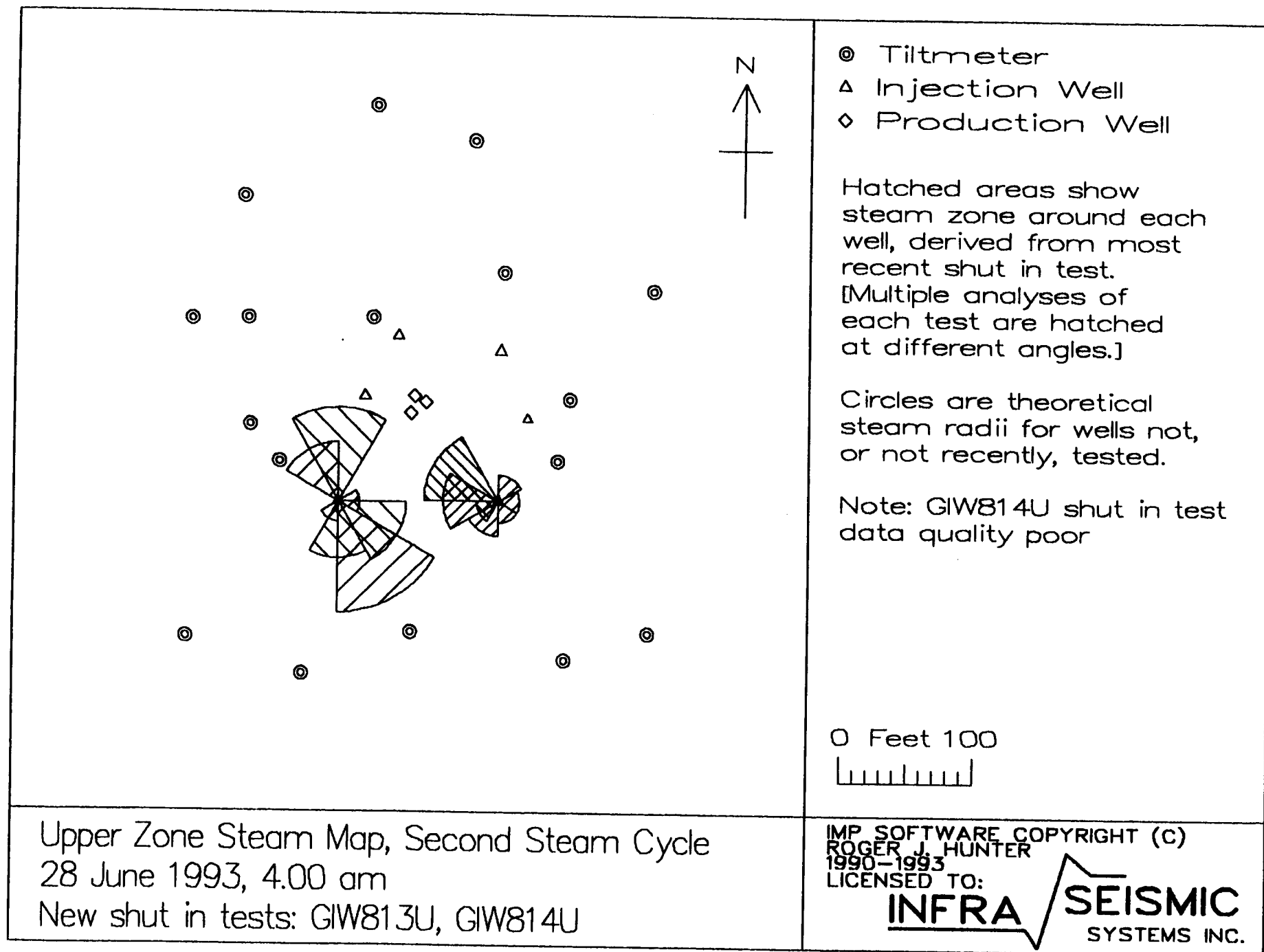


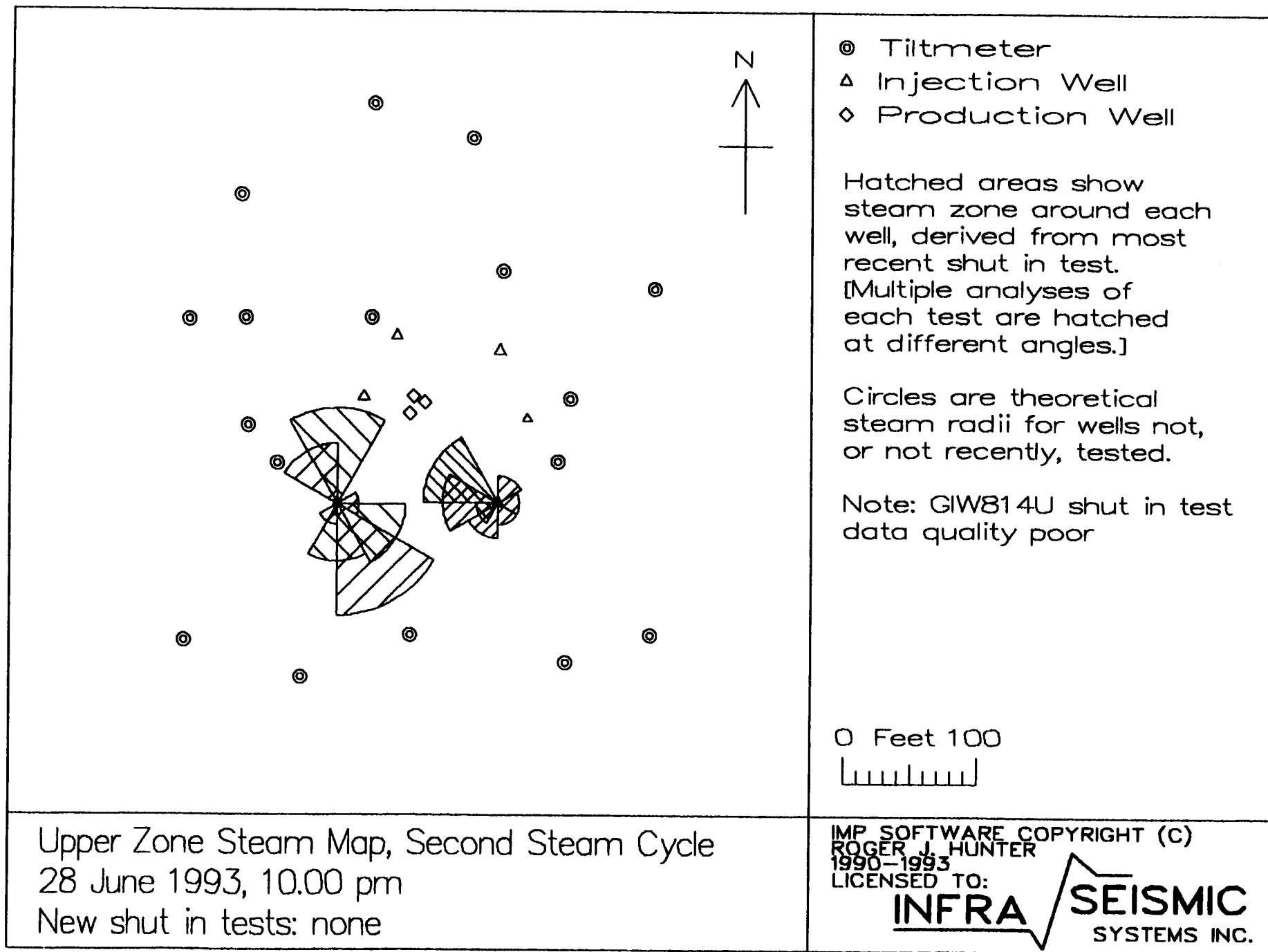


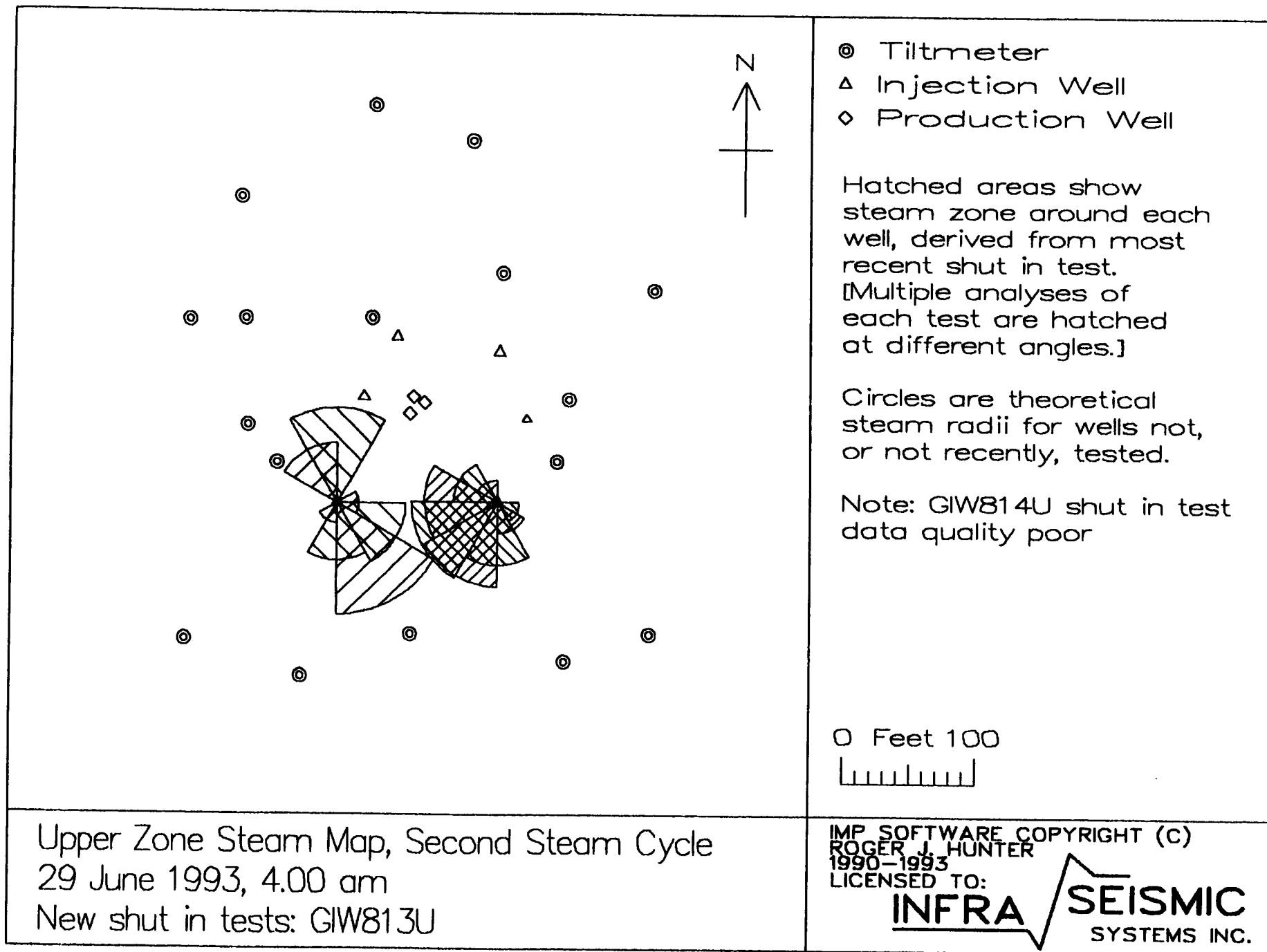


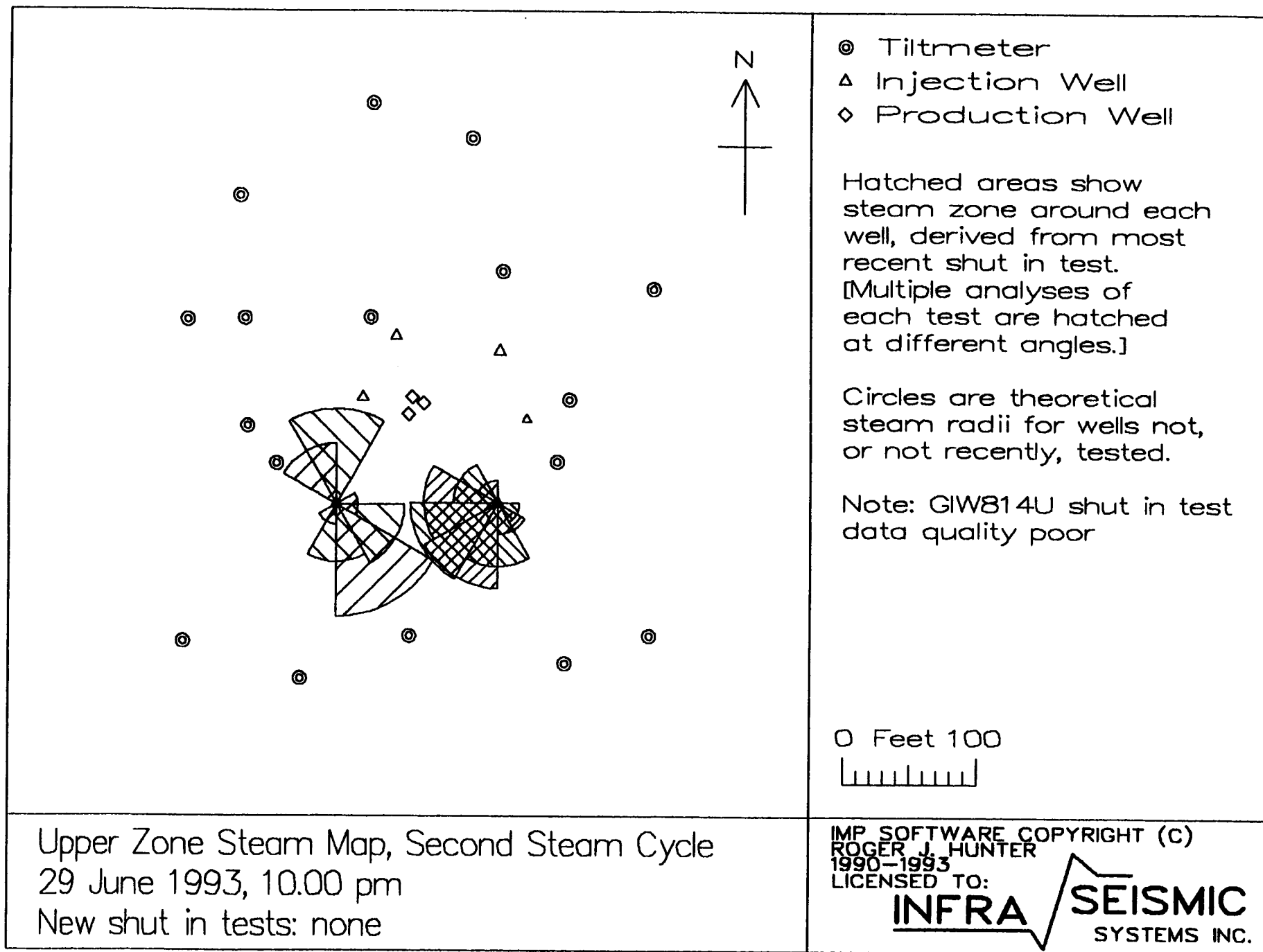












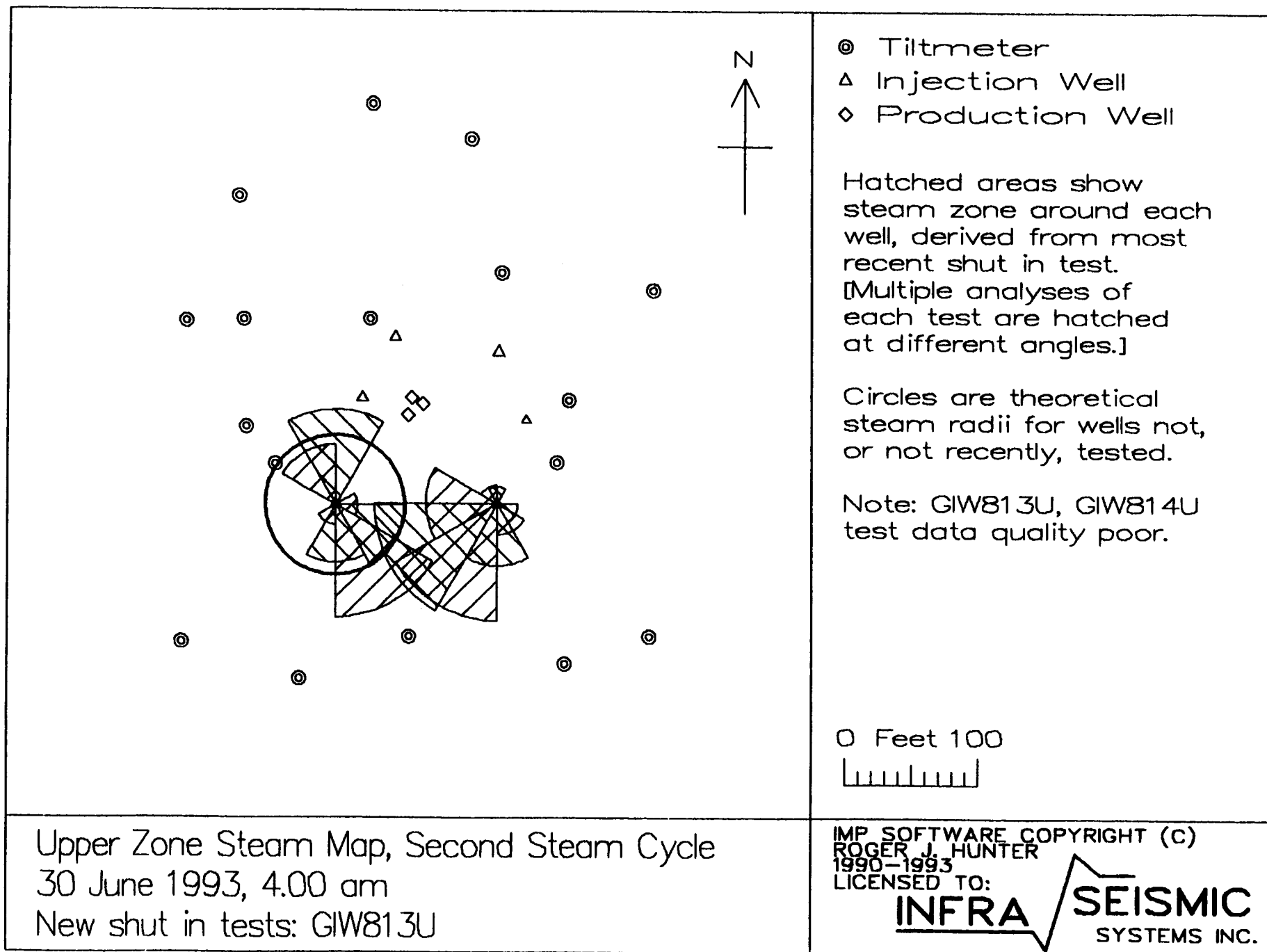
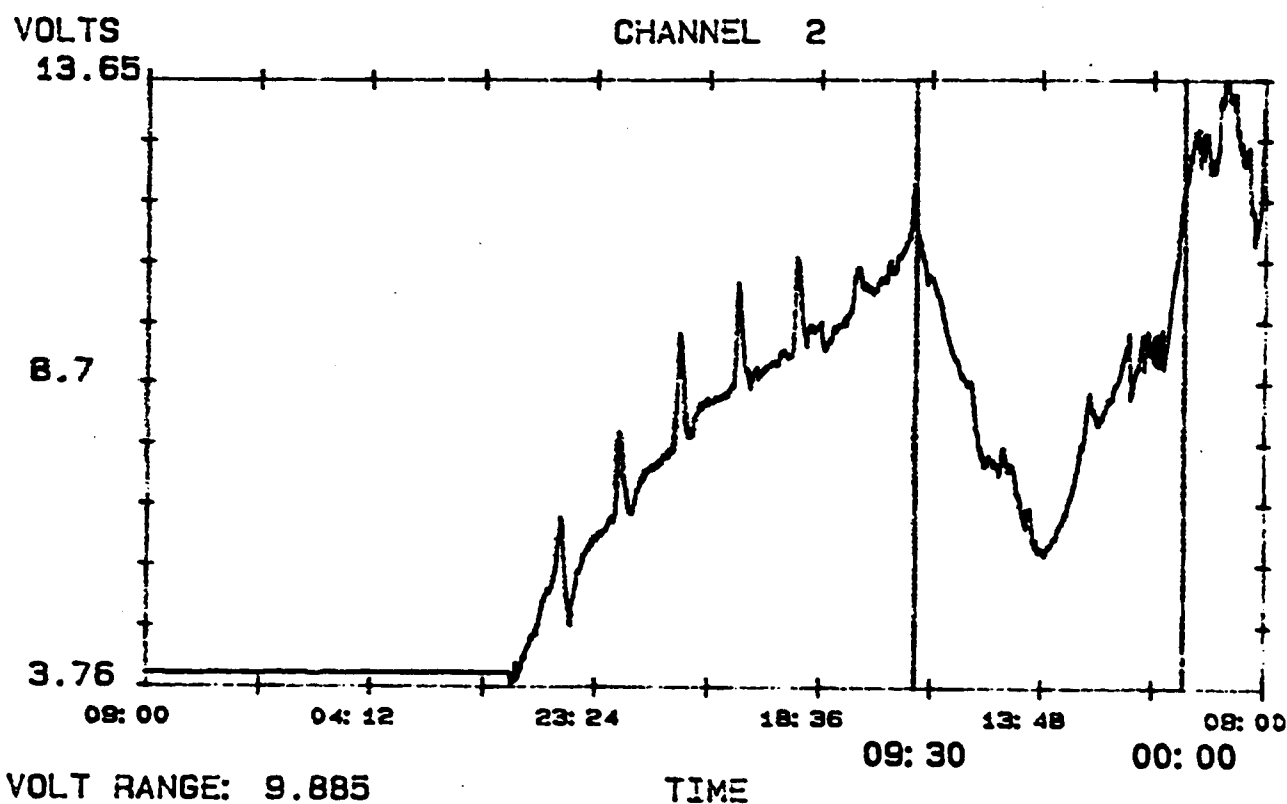
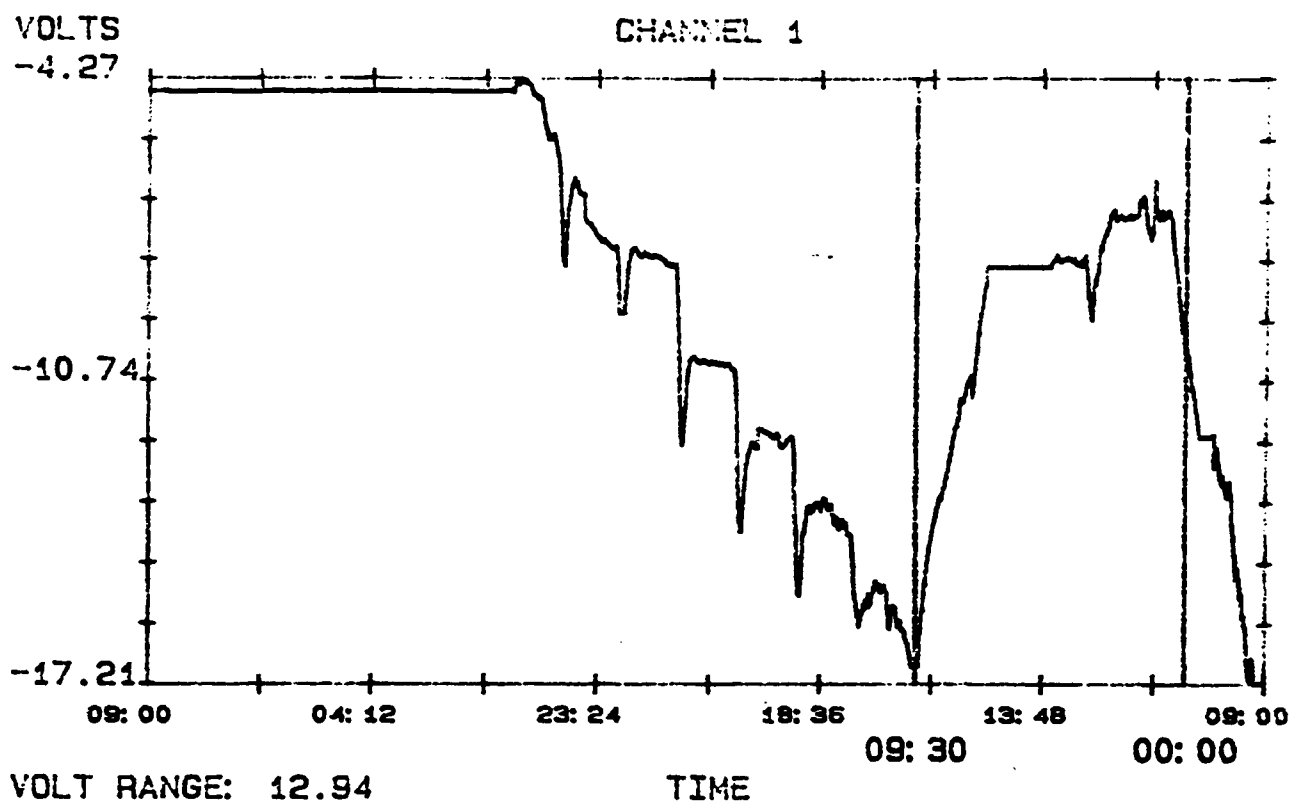


Figure 77



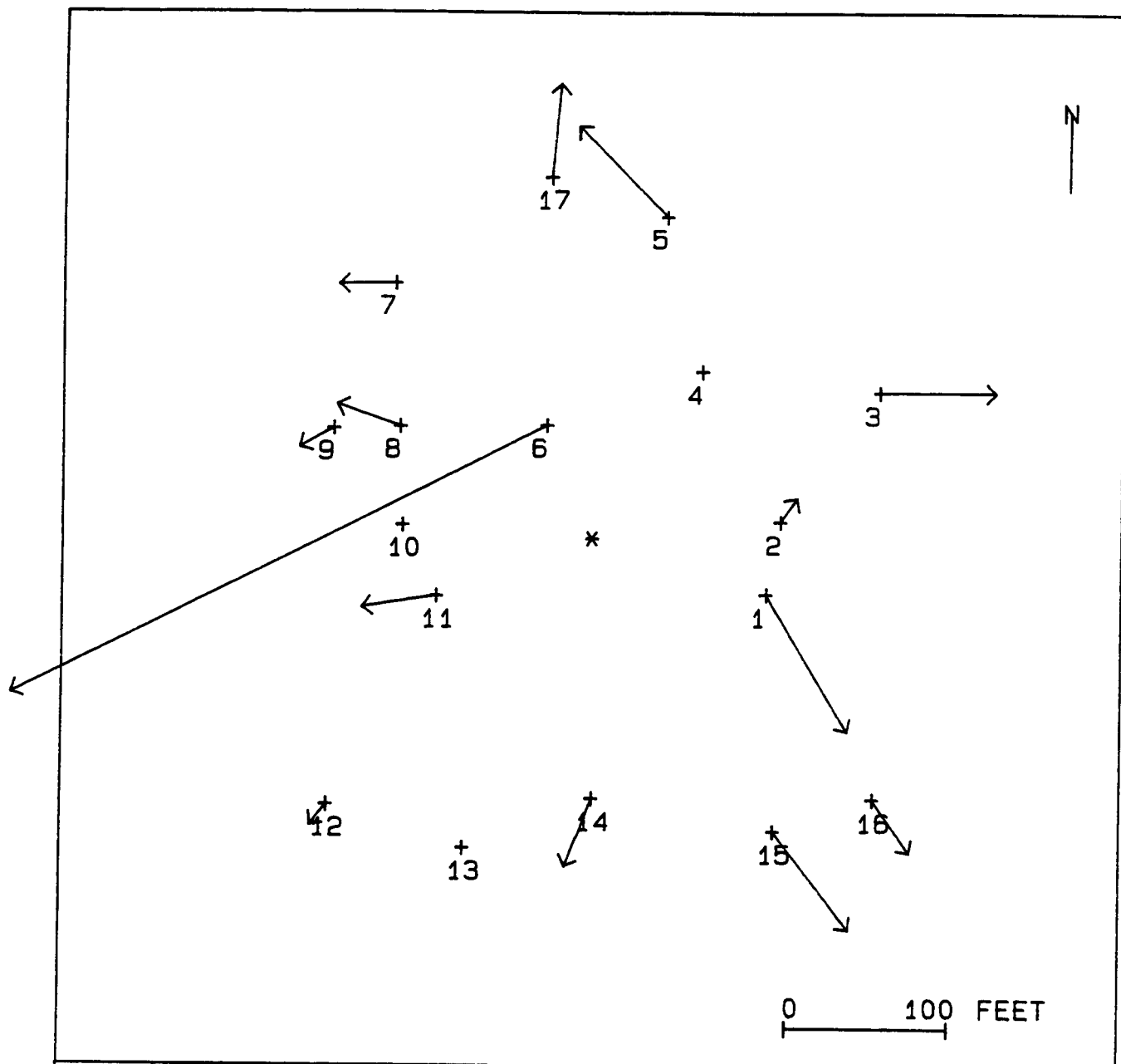
VOLT RANGE: 9.885

TIME

INFRASEISMICS 1993

START 01: 22: 09: 00:
STOP 02: 10: 09: 00:
EVENT (HR: MN) _____

Figure 78



DATE: 6/5/93

20 μ RAD
 REAL

LOWER ZONE, SECOND STEAM CYCLE
 Total tilt change since start of
 injection into GIW815L and GWI820L on
 6/2/93. (Star at centre of plot is well
 GEW816. Tiltmeters 4 and 13 not in use)

INFRASEISMICS 1993

APPENDIX A

ANALYSIS OF HYDROLOGIC TESTS

The tilt signal resulting from a pressure transient test is a function of a number of parameters, many of which may be unknown. Some may also be singular, or close to singular (i.e. it may be impossible to solve for one parameter without knowing or assuming the value of another). Singularity is not necessarily a significant problem, because if a value assumed for one is, say, too high, then the derived value for the other will be too low (assuming the singularity is a product of the two) and the overall result will be the same. A problem occurs only if the derived value is used in a different context. In this respect the analysis of tilt data is similar to traditional well test analysis in which the pressure recorded in the well bore is analysed. In an inhomogeneous reservoir, traditional methods have an additional problem of non directionality.

For analysis of the tilt data, values were assumed for all parameters except: permeability, compressibility, and distance from the well to a no flow boundary if such existed within the radius of investigation. The data was analysed for variations in these parameters in each of six directions from the well.

In addition to achieving a best fit to the tilt data, the best fit to the total volume injected and the final flow rate was sought.



During the injection tests, pressure changes were monitored at eleven other wells. A second analysis of each injection test was performed which included fitting these pressure changes as well as the tilt and flow data. There were two problems associated with this analysis. First, the monitoring wells were typically clustered, with a large number in one direction and none in another, which tended to skew the fit. Second, parameters which are close to singular in pressure analysis may not be so in tilt analysis. This yields the problem described above, namely that the values of parameters derived from pressure analysis may not be suitable as base values for tilt analysis if values for the other parameters have had to be assumed.

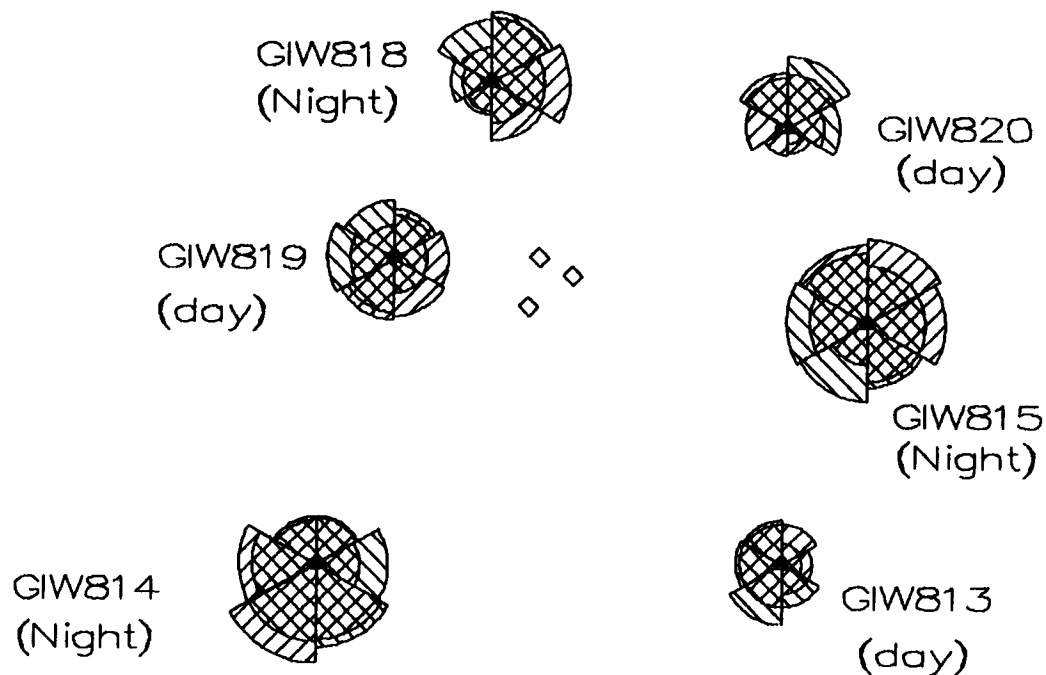
The first three tests were performed during the working day, while the latter three were performed at night. The night time test data was of better quality, due to the reduced industrial noise. In retrospect, duplicate tests would have been desirable, to check for repeatability.

Only one test was performed in the upper zones, and that during the day. This test has not been analysed.

Figure A1 shows the results of the analyses. The 'reservoir quality' is taken as the net flow in each direction during the injection test, and the hatched areas are proportional to the net flows. Figure A2 is an exaggerated version of the same data, for illustration only, with hatched areas proportional to the square of the net flows. Injection pressures were similar for all the tests.

The areas around GIW815L and GIW819L appear to be rather homogeneous, while the other four tests seem to show preferential flow directions (generally North and East for GIW818L and GIW20L; and South and West for GIW813L and GIW814L). The analyses indicated significant variations in reservoir properties, and flow in some directions does appear to be restricted, but there was little indication of any sealing barriers within the area of the tiltmeter array. There was some evidence of a discontinuity a few hundred feet South and East of GIW813L.

-  Tilt data only
-  Tilt and Pressure data




- △ Injection Well
- ◇ Production Well

Hatched areas are proportional to apparent fluid flow in each direction during 1 hr injection test.

Note 1: Night time test data is generally more reliable than that from day time tests.

Note 2: GIW820L test data quality poor.



0 Feet 50

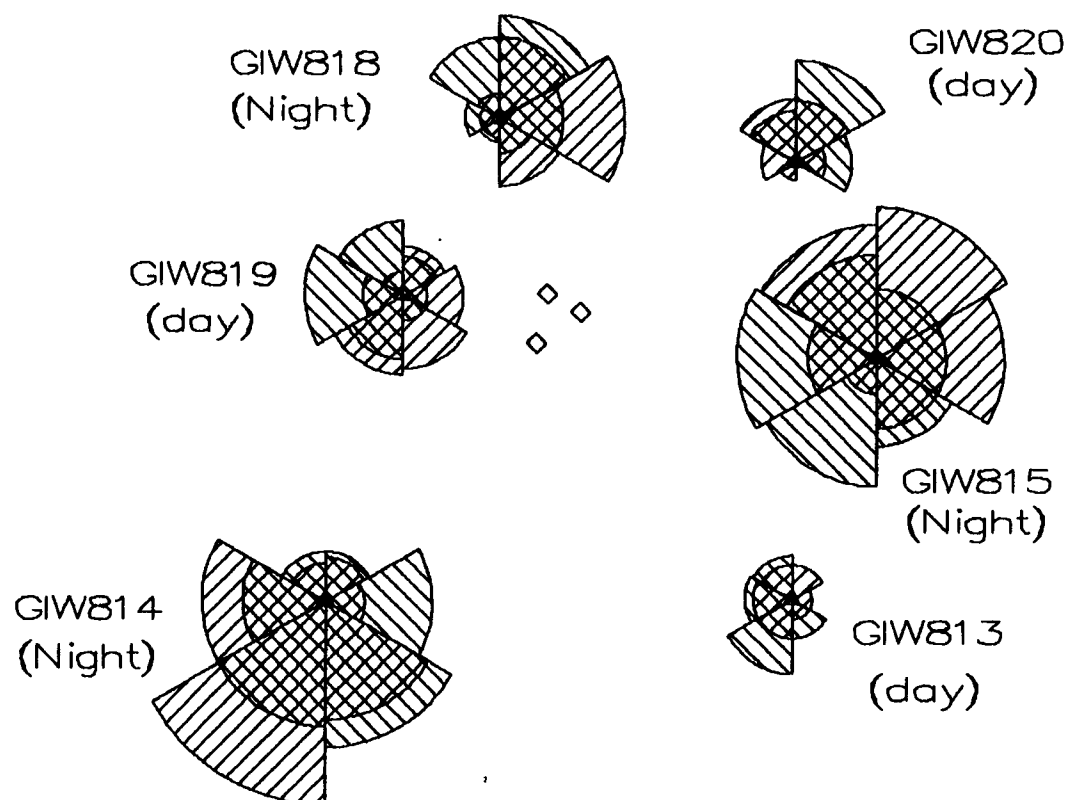


Lower Zone Reservoir Quality
derived from tiltmeter mapping of
hydrologic tests.

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-  Tilt data only
-  Tilt and Pressure data



- △ Injection Well
- ◇ Production Well

Radii are proportional to apparent fluid flow in each direction during 1 hr injection test.

Note 1: Night time test data is generally more reliable than that from day time tests.

Note 2: GIW820L test data quality poor.

0 Feet 50


Lower Zone Reservoir Quality derived from
 Tiltmeter Mapping of Hydrologic Tests.
 EXAGGERATED — NOT TO SCALE

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